Series II, Volume 2 November 29, 1957 Number 7

# BULLETIN

OF THE

## AMERICAN PHYSICAL SOCIETY

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INCLUDING THE

PROGRAMME OF THE

## 1957 THANKSGIVING MEETING

AT

ST. LOUIS, MISSOURI

November 29 and 30, 1957

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# BULLETIN

of the

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November 29, 1957 Series II, Vol. 2, No. 7

# BULLETIN

OF THE

# AMERICAN PHYSICAL SOCIETY

1957 Thanksgiving Meeting, St. Louis, Missouri, November 29–30, 1957

THIS is one of the years in which the **Thanksgiving Meeting of the American Physical Society is held in St. Louis.** There have been two others—1945 and 1952—since World War II. The dates are **Friday and Saturday, November 29 and 30.** Our host as heretofore is Washington University, and our previous experiences augur a happy meeting. The University is in the western part of St. Louis, opposite the northwest corner of Forest Park. The Chairman of the Local Committee is Professor John M. Fowler. The programme is almost equally divided between nuclear and theoretical physics on the one hand, solid-state physics on the other. It is not many years since people were complaining that our meetings were devoted almost wholly to nuclear physics: how great the change!

**Hotel.** The official hotel is the Coronado, on Lindell Boulevard at Spring Street, roughly midway between the Union Station and the University. A uniform rate of $7 for single and $13 for twin-bed rooms is offered to our members, who must make their own reservations as promptly as possible, saying that they are coming to our meeting and stating their expected times of arrival and departure. Single rooms are limited in number, and those who are not prompt in reserving stand a better chance of getting a bed if they are willing to share a double or a suite. Remember that hotels do not generally hold rooms into the evening hours unless evening arrival has been specified in the letter of reservation.

From the Coronado to Washington University one may go by taxi, bus, or streetcar. Taxi fare is estimated at $1.55 and the ride takes about twenty minutes. Ask the driver to go to the Women's Building of Washington University. The bus, No. 93 marked "Lindell-Wydown," is boarded immediately in front of the hotel, and the place to get off is Skinker and Millbrook. The streetcar, No. 11 marked "University," is boarded at Spring and Olive Streets, one block north of the hotel, and the place to get off is the "midway" stop opposite the north side of the campus. The direction is westbound, and the time is about forty minutes by either bus or streetcar. Guideposts will be placed at the bus and car stops where you get off.

**Registration.** The registration desk will be located in the Women's Building (not in Wayman Crow, the physics building, as at our latest previous St. Louis meetings). All members and guests are asked to register and to pay the modest registration fee of one dollar. Banquet tickets will be sold at the desk, and nearby there will be blackboards for announcements of the post-deadline papers if any, of the after-dinner speakers, of messages addressed to our members, and of any corrections to the text of this Bulletin.

A notable group of **invited papers on the general programme** is distributed largely among three symposia: one on nonconservation of parity (Friday morning), one on superconductivity (Friday afternoon), and one on design and utilization of high-energy accelerators (Saturday morning). For these and other suggestions the Society is indebted to a Committee of Midwestern physicists chosen for the purpose. Other invited papers are scheduled for Session B on Friday morning and elsewhere in juxtaposition with ten-minute papers on similar topics. The papers on neutron physics result from the International Conference held at Columbia University in September.

Our **Division of Solid-State Physics has arranged a Symposium** on solid-state information from low-temperature experiments; it is scheduled for Saturday afternoon. Its affinity with the Symposium on superconductivity is unplanned but not unwelcome.

**One hundred and sixteen contributed papers** are distributed among twelve sessions. It was not possible to avoid competition between solid-state programmes, so many of these there are. Session H affords striking evidence that the subject here

called "radio-frequency spectroscopy" extends all the way from nuclear physics to solid-state physics. The Friday morning sessions begin as late as reasonably feasible in order to afford time for our members to register and buy their banquet tickets. The Saturday sessions begin relatively early for the benefit of those who feel themselves unable to remain in St. Louis over Saturday night.

The **banquet** will be held on Friday evening at 7:30 in the Ballroom of the Coronado Hotel. The after-dinner speakers will be E. U. Condon, Chairman of the Department of Physics at Washington University; A. H. Compton, who as Chancellor of the University was our host in 1945 and 1952; and John P. Hagen of Project Vanguard. The price of the banquet will be $4.00, including taxes and tips. Since this is a two-day meeting and the banquet is held on the first day, there is not much time for buying tickets. Use the form on page 364 if possible, and if not, **see to the purchase of the tickets in the early hours of Friday morning.** The deadline hour for purchase of tickets (perhaps no later than twelve noon) will be announced on the blackboard near the registration desk. Attendance at the banquet should be regarded as a part of the professional obligations of the physicist, as it evidently is in the great engineering societies in spite of prices much higher.

**Post-deadline ten-minute papers,** pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society (the address below) not later than Friday, November 22. The abstracts must be composed according to the usual rules, and two copies must be submitted of each: they will not be published. The titles of such papers as may be accepted will be written on a blackboard near the registration desk, and these papers will be scheduled for presentation at the end of Session U.

The **Council of the Americal Physical Society** will meet in Room 210 Louderman Hall at 4.00 P.M. on Friday unless contrary notice is distributed to its members.

**Prospective meetings and deadlines** for the Season 1957–1958 are listed on page 362 of this Bulletin.

**Instructions for the preparation of abstracts** are printed on page 362 of this Bulletin. This is **required reading.** The regulations become more numerous and more stringent as the years go by, for their purpose is to shorten the period which the text of the Bulletin must spend in the hands of the editorial staff of the American Institute of Physics before it goes onward to Lancaster Press, and this becomes more urgent as our Bulletins fatten. A new one has been introduced which will cost money to those who do not notice it. Read and heed!

**Errata** pertaining to abstracts in this issue will be published in a later issue of this Bulletin if received not later than Monday, December 2, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York (note new address!) Do not send the abstracts marked with corrections: write "instead of . . . read. . . ." Add nothing. The privilege of publishing an erratum is not accorded in order to enable people to publish new data or to restore material cut out because the abstract was too long.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University,
New York 27, New York

# EPITOME OF THE 1957 ST. LOUIS MEETING

(Personal names are those of invited speakers, except at the ends of lines where they are the names of halls.)

## Friday Morning

10:15 A. Apparatus of nuclear physics. Wilson.

10:30 B. Barker, Lin, Keesom. Louderman.

10:30 C. Metals. Wayman Crow 101.

10:00 D. Nonconservation of parity: Case, Jackson, Frauenfelder, Krohn. Brown Auditorium.

## Friday Afternoon

2:15 F. Beta decay; Pond, Millett. Wilson.

2:00 G. Liquids and solids; Delbecq. Wayman Crow 101.

2:15 H. Radio-frequency spectroscopy. Louderman.

2:15 J. Superconductivity: Bardeen, Garfunkel, Morse, Slichter. Brown Auditorium.

## Friday Evening

7:30 Banquet of American Physical Society: Condon, Compton, Hagen. Coronado Hotel.

## Saturday Morning

9:30 L. Semiconductors and insulators. Brown Auditorium.

9:30 M. Scattering and polarization; mesons; cosmic rays. Wilson.

9:30 N. Reactions of transmutation and nuclear energy levels. Brown 118.

9:30 P. Design and utilization of high-energy accelerators: Kerst, Foss, Wright, Crewe. Louderman.

9:30 Q. Theoretical physics, I. Wayman Crow 101.

## Saturday Afternoon

1:30 R. Division of Solid-State Physics: Solid-state information from low-temperature physics: Glover, Koenig, McClure, Holmes. Brown Auditorium.

1:30 S. Irradiation effects. Wilson.

1:30 T. Neutron physics: Cameron, Schultz, Bollinger. Louderman.

1:30 U. Theoretical physics, II. Post-deadline papers, if any. Wayman Crow 101.

# PROGRAMME

FRIDAY MORNING AT 10:15

Wilson Auditorium

(N. HILBERRY presiding)

## *Apparatus of Nuclear Physics*

**A1. Computational Study of a Spirally Ridged FFAG Accelerator.*** L. JACKSON LASLETT, *Iowa State College*, A. M. SESSLER, *The Ohio State University*, AND J. N. SNYDER, *University of Illinois*.—Preparatory to construction of a spirally ridged[1] electron model, now in operation, trajectory studies for proposed structures were made with the ILLIAC to determine oscillation frequencies and stability limits. The magnetostatic potential of the scaling field ($\langle H \rangle \propto r^k$), arising from a magnet structure whose dimensions and excitation are consistent with the scaling property of the field, was obtained by relaxation on a *two-dimensional* net by exploiting the scaling character of the field. Trajectory computations were made by reference to the scaled potential stored, as half-words, in the fast memory of the computer. Various possible misalignments, such as the displacement of one magnet sector, were simulated by periodic introduction of simple algebraic transformations. Initially proposed structures with $N/4 < \nu_r < N/3$ and operating near the $\nu_r = 2\nu_z$ resonance exhibited stability limits which were undesirably curtailed when a vertical sector displacement as small as $r/300$ was introduced. The final parameters proposed for a separated-sector model were $k = 0.7$, $1/w = 6.25$, $N = 6$, rms flutter $\cong 1.08$, $\nu_r = 1.40$, and $\nu_z = 1.12$. Radial amplitudes in excess of $r/10$ and axial amplitudes as large as $r/15$ then appeared permissible.

* Work performed at the University of Illinois for the Midwestern Universities Research Association, assisted by the National Science Foundation, the Office of Naval Research, and the U. S. Atomic Energy Commission.

[1] Symon, Kerst, Jones, Laslett, and Terwilliger, Phys. Rev. **103**, 1837 (1956).

**A2. Construction of the Spiral Sector FFAG Model Accelerator.*** H. J. HAUSMAN,† E. A. DAY, R. O. HAXBY,‡ D. W. KERST,§ F. E. MILLS, AND F. L. PETERSON, *Midwestern Universities Research Association*.—A spiral sector FFAG model betatron has been designed and constructed to accelerate electrons from 25 kev to 118 kev. The radial dependence of the magnetic fields in the six-sector model is given by $H = H_0(R/R_0)^{9.7}$. The direction of the magnetic field throughout the machine is in the same sense. Axial stability is provided by edge focusing. Pertinent magnet dimensions such as vertical aperture are scaled to be proportional to machine radius, and at all radii the spiral magnet sector edges make a fixed angle, 43°50′ for this model, with circles about the machine center. The increase of field with radius is achieved by distributed pole face windings. The average field at the injection radius of 30 cm is 16.5 gauss increasing to 23.9 gauss at 51.5 cm. The vertical magnet aperture increases from 7.9 cm to 13.5 cm in the same range. Alternate gradient focusing is designed to give 1.398 radial and 1.125 vertical betatron oscillations per revolution. Tuning coils are provided for investigations of machine behavior in the vicinity of various resonances. Details of magnet design and construction will be described.

* Supported by the Office of Naval Research, National Science Foundation, and the U. S. Atomic Energy Commission.
† The Ohio State University.
‡ On leave from Purdue University.
§ Now at General Atomic.

**A3. Magnetic Measurements on the Spiral Sector FFAG Model Accelerator.*** R. O. HAXBY, D. W. KERST,† F. L. PETERSON, E. M. ROWE, R. STUMP,‡ AND W. A. WALLENMEYER, *Midwestern Universities Research Association*.—Calculations on the FFAG spiral sector model showed that only small variations from the design values of the field were permitted. Therefore, careful field measurements and corrections were necessary. The vertical field components were measured initially with a flip coil. Later a peaker strip magnetometer was used.[1] The accuracy of these measurements was at least $\pm 0.05$ gauss. The value of $k$ along the median spiral of each sector was measured with a three-coil system.[2] The median plane of the machine was determined with the aid of a sensitive magnetometer. This device would detect fields in the order of a milligauss. Corrections were made in the vertical field by redistributing the forward windings on the back legs of the magnets and by adding extra windings to compensate for the reluctance of the iron. Corrections in the median plane were made by tilting and varying the height of the magnet sectors and by adding additional correction windings.

* Supported by the U. S. Atomic Energy Commission.
† Now at General Atomic.
‡ University of Kansas.
[1] Ferdinand Voelker and Minard A. Leavitt, UCRL 3084 (1955).
[2] Cole, Haxby, Jones, Pruett, and Terwilliger, Rev. Sci. Instr. **28**, 403 (1957).

**A4. Injection in the Spiral Sector FFAG Model Accelerator.*** D. W. KERST† AND F. E. MILLS, *Midwestern Universities Research Association*.—To achieve injection into the spiral sector model, 25-kev electrons from an electron gun are deflected by an electrostatic inflector onto paths parallel to the equilibrium orbits of the accelerator. The electron gun has optics similar to those of conventional betatron injectors. The inflector is so arranged that particles can be deflected onto orbits with betatron oscillation as small as 0.25 mm. The injection system has a radial emittance of 0.004 cm radian and a vertical emittance of 0.07 cm radian. Accelerated beams of $6 \times 10^9$ electrons have been observed, corresponding to acceleration of 2% of the total charge injected in a 4-$\mu$sec burst.

* Supported by the U. S. Atomic Energy Commission.
† Now at General Atomic.

**A5. Frequency Measurements and Resonance Survey in the Electron Model Spiral Sector FFAG Accelerator.*** R. STUMP,† B. WALDMAN,‡ AND W. A. WALLENMEYER, *Midwestern Universities Research Association*.—Beam intensities, vertical and radial betatron oscillation frequencies, and stop bands in the tuning range of the spiral sector FFAG accelerator were measured. The machine is tunable from $\nu_z = 0.46$ to 1.76 and $\nu_z = 1.12$ to 1.71. In this tuning region the resonances $\nu_z = 1$, $\nu_z = 0.5$, $\nu_z = 1.5$, $\nu_z = 1.5$, $\nu_z + \nu_z = 2$, and $2\nu_z + 2\nu_z = 6$ are observed to destroy the beam. Of these only $\nu_z = 1$, $\nu_z = 0.5$, and $2\nu_z + 2\nu_z = 6$ cause complete loss of beam at all points in the available tuning range. The Walkinshaw

resonance ($2\nu_z - \nu_x = 0$) appears as a minimum of beam intensity.

* Supported by the U. S. Atomic Energy Commission.
† University of Kansas.
‡ Notre Dame University.

**A6. $\nu_x = \frac{1}{4}N$ Nonlinear Resonance in AG Accelerators.*** G. PARZEN,† *Midwestern Universities Research Association.*—The $\nu_x = \frac{1}{4}N$ nonlinear resonance in the betatron oscillations of the strong-focusing AG accelerator has been investigated for a general class of magnetic fields. It is believed that the method used can be extended to treat any magnetic field. The method used reduces the problem to an eigenvalue problem of the kind usually met in solid-state theory. The location and the stability limits of the nonlinear resonances becomes equivalent to finding the gaps in what corresponds to the allowed energy levels of the system. The gaps in the energy levels are found by a procedure similar to the weak binding approximation in solid-state theory. The results of the method for the $\nu_x = \frac{1}{4}N$ will be given for a general class of magnetic fields.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Notre Dame.

**A7. Design of Regenerative Extractors for Synchrocyclotrons.*** WARREN FENTON STUBBINS, *University of California, Berkeley.*—The regenerator, a magnetic perturbation in the rapidly falling cyclotron edge field, is specified from the characteristics of unperturbed radial oscillations in the falling field and the extraction requirement that the radial oscillations about the synchronous orbit have an arrested node. The radial-momentum change at the regenerator is that which produces orbits having an arrested node and is proportional to the integrated value of the perturbation in gauss radians. The regenerator position relative to the fixed node governs the rate of growth in amplitude of radial oscillation. The strongly coupled axial and radial oscillations depend on the edge field and the regenerator perturbation. Axial loss rate and aperture for regenerated beam are analyzed to provide criteria for magnetic field shape in the extraction region and the regenerator position. The momentum spread of extracted particles and bounds on the regenerator shape to retain regenerating particles are determined. Stepwise integrated orbits establish regenerator specifications for the 184-in. cyclotron. Predicted radial increase and axial oscillation behavior are observed in computed regenerating orbits. The regenerator is successfully removing particles from the 184-in. cyclotron.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**A8. New Fast Chopper for Transmission Measurements.*** G. E. THOMAS, L. M. BOLLINGER, R. E. COTE, AND T. J. KENNETT, *Argonne National Laboratory.*—A new time-of-flight spectrometer for neutron transmission measurements has been put into operation. The rotor for this new system is 10 in. in diameter, the inner 6-in. core being fabricated from uranium, and the outer portion from Monel metal. One set of seven slits, each 0.045 in. wide at the center and 0.015 in. at the outside and 2 in. high, traverse the rotor perpendicular to the axis of rotation. The burst width is roughly 1.5 μsec. This complex slit shape was formed in the solid metal by an electrical discharge method. The detector is a boron-loaded liquid scintillator with an active area 3.5 in. by 16 in. It has an efficiency of 30% at 1 kev. With this system, using a 120-meter flight path at an energy of 1 kev, one obtains about 5 counts per minute per μsec of channel width. The over-all resolution is in the range of 0.01 to 0.015 μsec per meter. Some transmission measurements obtained with this system will be presented.

* Work done under the auspices of the U. S. Atomic Energy Commission.

**A9. New Electrostatic Generator.*** I. MICHAEL, E. D. BERNERS, M. C. COX, R. H. DAVIS, A. S. DIVATIA, F. J. EPPLING, R. W. HILL, D. J. KNECHT, J. N. MCGRUER, L. C. NORTHCLIFFE, AND R. G. HERB, *University of Wisconsin.*—Both support column and accelerating tube are constructed of metal hard-soldered to ceramic. The tube is 5 ft long and is evacuated by an Evapor-ion pump. Without the tube the generator has been operated in excess of 7 Mv. With flat disk Mo electrodes in the accelerating tube usable voltage was limited to about 2.1 Mv. These electrodes were replaced with steel disks having side pump-out holes. Beam apertures are tapered from $\frac{1}{4}$ in. diameter at the high voltage end to $\frac{1}{8}$ in. diameter halfway down the tube, and from there on the bore is uniform. For a short interval the tube was operated at 4 Mv with a beam, and no small discharges or electron loading were observed. A few tube ceramics have been damaged in these tests, and further tests must wait until better spark gap protection is provided. The charging belt is equipped with paper staples which are charged by induction. Operation is very stable.

* Work supported by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation, by the U. S. Atomic Energy Commission, and by the National Science Foundation.

**A10. Negative Helium Ion Source.*** P. F. DAHL, K. J. BROSTROM,† L. P. GREENE,‡ R. G. HERB, AND E. C. PETERSON, *University of Wisconsin.*—A negative ion source has been developed for the production of $He^-$ ions, from which 0.05 microampere of $He^-$ ions and 50 microamperes of $H^-$ ions have been obtained. Positive ions are extracted from an ion source and are accelerated by 30 kv before traversing a canal containing gas, according to the practice used by Weinman and Cameron.[1] Following charge exchange the ion beam is focused by an electrostatic Einzel lens, magnetically analyzed, and brought to a $\frac{1}{4}$-in. diam spot in a Faraday cup, while secondary electrons are electrostatically suppressed. A pressure less than $10^{-4}$ mm Hg is maintained in the apparatus by an Evapor-ion pump. Hydrogen, helium, nitrogen, and argon have been tried as converter gases. Maximum yield was obtained with nitrogen as converter in a kerosene cooled copper canal 1.25 in. × 0.110 in. Measurements indicate that charge exchange equilibrium is approached with a gas flow of about 50 atmos cc/hr.

* Work supported by the National Science Foundation and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
† At Universitetets Institut for Teoretisk Fysik, Copenhagen.
‡ Now with Convair.
[1] J. A. Weinman and J. R. Cameron, Rev. Sci. Instr. **27**, 288 (1956).

**A11. Hybrid Variable Energy Proton Accelerator and Negative Hydrogen Ion Source.*** J. A. WEINMAN, P. M. WINDHAM,† AND H. L. HANEY,‡ *University of Wisconsin.*—Protons with continuously variable energy exceeding that obtained from electrostatic generators may be produced by the following method: $H^-$ ions could be injected into a linear accelerator. The $H^-$ ions emerging from the linear accelerator with energy $E$ could then be fed into a "tandem" electrostatic accelerator. The $H^-$ ions would be stripped of electrons inside the high-voltage electrode at potential $\pm v$, and the resulting proton would emerge at ground potential with energy $E \pm 2$ ev. Such a hybrid accelerator requires an intense $H^-$ ion beam during the "on" part of the linear accelerator duty cycle. An $H^-$ ion source similar in principle to an earlier Wisconsin[1] source but of improved design has been constructed: The positive ion source is a water-cooled magnetic ion source. The gas target for charge exchange is kerosene cooled. Gas from the ion source is pumped by an Evapor-ion pump with a speed for hydrogen of 15 000 liters/sec.

* Work supported by the National Science Foundation and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
† At North Texas State College, Denton, Texas.
‡ At Judson College, Marion, Alabama.
[1] J. A. Weinman and J. R. Cameron, Rev. Sci. Instr. **27**, 288 (1956).

FRIDAY MORNING AT 10:30

Louderman Auditorium

(R. N. VARNEY presiding)

### *Invited Papers*

**B1. Some Theoretical Aspects of the Overhauser Effect.** W. A. BARKER, *St. Louis University.* (20 min.)

**B2. Internal Rotation of Molecules by Microwave Spectroscopy.** C. C. LIN, *University of Oklahoma.* (30 min.)

**B3. Specific Heat of Semiconductors at Very Low Temperatures.** P. H. KEESOM, *Purdue University.* (30 min.)

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FRIDAY MORNING AT 10:30

Wayman Crow, 101

(D. K. HOLMES presiding)

### *Metals*

**C1. Thermoelectric Power of Dilute Indium-Tin Alloys.** E. I. SALKOVITZ AND ERWIN W. KAMMER, *U. S. Naval Research Laboratory.*—As a natural extension of previous work on the electron transport properties of dilute magnesium alloys,[1] a similar program is underway on dilute indium alloys. For this purpose a series of dilute binary alloys have been vacuum-cast and swaged into wires. This abstract concerns thermoelectric power measurements made on a series of dilute indium-tin alloys from 77°K to room temperature. For alloys containing 1.5 atomic precent tin or less the thermal c.m.f.'s measured relative to pure indium go through minima followed by maxima, the magnitudes of which depend upon composition. Alloys richer in tin, up to at least 2.9 atomic percent, do not show the minima but do show the maxima. At 77°K the relative thermoelectric power is approximately linear with composition. As the temperature is raised, however, the thermoelectric power goes through a minimum. The higher the temperature, the higher is the tin composition at which the minimum occurs. In making the measurements considerable care has been exercised to avoid the effects of tension upon the samples, which are very soft. In some cases the tension coefficient of the thermoelectric power has actually been measured and found to be significant.

[1] Salkovitz, Schindler, and Kammer, Phys. Rev. **105**, 887 (1957).

**C2. Residual Resistivity of Noble Metal Alloys.** F. J. BLATT, *Michigan State University.*—It is well known that the residual resistivity of dilute alloys of the monovalent metals depends on the difference in valence of the solvent and solute atoms: the residual resistivity per atomic percent solvent is approximately proportional to the square of the valence difference. In addition to this dependence these alloys also exhibit a dependence on the row of the periodic table which the solute atom occupies. It appears that, for constant valence, the residual resistivity decreases as the atomic weight of the solute increases. This "period dependence" will be discussed in terms of a modification to the Friedel rule suggested by Harrison. It will be shown that the period dependence is closely related to the lattice strain about the solute atoms. Results of calculations will be presented and compared with the experimental data. Applications of the model to other problems of electronic structure of alloys will be discussed.

**C3. Anisotropic Thermal Expansion of Bismuth.** E. F. CAVE AND L. V. HOLROYD, *University of Missouri.*—The anisotropic linear thermal expansion of bismuth has been measured by x-rays and mechanical means. No discontinuity has been found in the temperature range investigated and no decline in the expansion constant near the melting point has been found, as has been reported in earlier work. The Gruneisen relation is obeyed to the approximation that $C_p$ equals $C_v$.

**C4. Specific Heat of High-Purity Iron by a Pulse-Heating Method.** D. C. WALLACE, P. H. SIDLES, AND G. C. DANIELSON, *Iowa State College.*—A dynamic pulse-heating method has been developed for measuring the specific heats of metals with an error of less than two percent from room temperature to 1000°C. A thin wire sample, enclosed in a vacuum furnace, was connected in a Kelvin bridge and the bridge was balanced. A pulse (40 msec) from a constant voltage supply was applied to the bridge. This pulse heated the sample (approx 100°C), changed its resistance, and unbalanced the bridge. The resistance unbalance, along with suitable time markers, was displayed on an oscilloscope and recorded photographically. The power input ($I^2R$) to the sample was calculated with the aid of unbalanced Kelvin bridge equations. The small heat losses ($dQ/dt$) due to radiation and end conduction were computed. In order to obtain the rate of temperature change ($d\theta/dt$) from the recorded resistance unbalance, the resistance of the wire was measured as a function of temperature. The specific heat was found from the equation $c_p = (I^2R - dQ/dt)/(m d\theta/dt)$, where $m$ is the mass of the sample. Results have been obtained for high-purity iron over the temperature range 50°C to 1920°C. Variations of the specific heat near the phase transitions were shown in detail.

**C5. $M_{2,3}$ Emission Spectrum of Copper.*** D. H. TOMBOULIAN AND D. E. BEDO,† *Cornell University.*—The copper $M_{2,3}$ band was investigated in connection with a sequential study of $M_{2,3}$ emission spectra of the 3*d* transition metals. The characteristic band is superimposed on the continuous spectrum emitted by the target. As observed, the underlying background consists of radiation appearing in the first order as well as shorter wavelengths diffracted in higher orders. The procedure adopted for background correction will be described. Some features of the photometrically determined

$I(E)/\nu^3$ distribution are as follows. The band has a maximum at 72.0 ev (172.2A) and excluding satellite structure has an over-all width of 16 ev. At the high-energy end, the intensity rises gradually and does not show the sharp edge structures which appear in the results of Gyorgy and Harvey[1] obtained by a recording spectrograph. The band shape derived from the present measurements closely resembles that reported in a previous photometric study[2] and is in agreement also with the recent work of Fisher, Crisp, and Williams[3] based on photomultiplier detection techniques.

* Supported in part by the Office of Ordnance Research, U. S. Army.
† Corning Glass Foundation Fellow.
[1] E. M. Gyorgy and G. G. Harvey, Phys. Rev. **87**, 861 (1952).
[2] Skinner, Bullen, and Johnston, Phil. Mag. **45**, 1070 (1954).
[3] Fisher, Crisp, and Williams, Optica Acta (to be published).

**C6. Small-Angle X-Ray Scattering from Plastically Deformed Copper and Nickel.** R. L. WILD, W. T. OGIER, AND J. C. NICKEL, *University of California, Riverside.*—The recently reported dependence of small-angle x-ray scattering on degree of plastic deformation in rolled nickel foil[1] has been observed also in electrolytically deposited foils of copper and nickel. Foils which have been stretched and then annealed above the recrystallization temperature show a characteristic increase in scattering at angles less than 0.02 radian (for copper $K\alpha$ radiation) when they are loaded beyond their elastic limit while in the x-ray beam. The scattering rise is unchanged if the load is subsequently removed and is similar to that previously observed from rolled and annealed nickel foils similarly stretched. Unannealed samples of the same foils fail to show the scattering rise when loaded under similar conditions up to the point of failure, which occurs at a stress nearly three times as great as that required to produce failure in the annealed samples or in similar rolled and annealed samples. Samples which are annealed but not previously strained show a somewhat smaller rise in scattering. These observations appear to strengthen the hypothesis that the observed scattering is due to dislocations.

[1] Wild, Ogier, and Nickel, Phys. Rev. (submitted for publication).

**C7. Small-Angle Scattering of X-Rays from Ellipsoids of Revolution.*** R. HIGHT AND P. W. SCHMIDT, *University of Missouri.*—The expression for the perfect-collimation x-ray small-angle scattering intensity from isolated, randomly oriented, ellipsoids of revolution involves an integral which must be evaluated by numerical methods. Malmon[1] has carried through a direct numerical integration for a wide range of shapes and scattering angles. The present paper deals with an approximation which is useful for the angular regions and ellipsoidal shapes for which direct evaluation of the integral is most difficult, namely, large scattering angles and large elongations. The method is based on the similarity between the perfect-collimation ellipsoidal scattering function and the scattering function for spheres with collimation by slits of infinite height and negligible width.[2] The results agree with Malmon's values in the region in which the calculations overlap.

* Work supported by the National Science Foundation.
[1] A. Malmon, Ph. D. thesis, University of Wisconsin (1957).
[2] P. W. Schmidt, Acta Cryst. **8**, 772 (1955).

**C8. Oscillatory Dependence of Thin Film Conductivity on Frequency.** P. J. PRICE, *IBM, Watson Laboratory.*—A conducting film at low temperatures may have an electron bulk mean free path large compared with its thickness $a$, so that the electrical conductivity is determined by scattering at the surfaces. Successive scattering events are then correlated in time, rather than random. It will be shown, by means of the Shockley-Chambers theorem,[1] that in consequence the high-frequency conductivity oscillates as a function of frequency $f$, approximately like a sinusoidal function of $2\pi fa/v$ where $v$ is the electron velocity at the Fermi level. The possibility of an experimental demonstration of this conclusion depends on realization of conditions where the penetration depth exceeds $a$ at the frequencies of interest. It appears that metals have too high an electron density.

[1] V. Heine, Phys. Rev. **107**, 431 (1957).

## FRIDAY MORNING AT 10:00

Brown Auditorium

(E. J. KONOPINSKI presiding)

### *Symposium on Nonconservation of Parity*

**D1. Present Status of Parity Conservation in Weak Interactions.** K. M. CASE, *University of Michigan.* (30 min.)

**D2. Theoretical Implications of Nonconservation of Parity in Beta Decay.** J. D. JACKSON, *University of Illinois.* (30 min.)

**D3. Experimental Status of Nonconservation of Parity in Beta Decay.** H. FRAUENFELDER, *University of Illinois.* (30 min.)

**D4. Nonconservation of Parity in the Decay of the Neutron.** V. E. KROHN, *Argonne National Laboratory.* (30 min.)

## FRIDAY AFTERNOON AT 2:15

Wilson Auditorium

(N. S. GINGRICH presiding)

### *Beta Decay*

**F1. Directional Correlation of the Gamma Rays of $Se^{76}$.*** E. G. FUNK, JR., AND M. L. WIEDENBECK, *University of Michigan.*—Directional correlation measurements have been made on the 0.65 Mev–0.55 Mev, 1.40 Mev–1.20 Mev, and 2.05 Mev–0.55 Mev gamma-ray cascades in $Se^{76}$. Previous investigations of the 0.65–0.55 correlation[1,2] had indicated an

assignment of 2+ to the first two excited states (assuming 0+ for ground state), with a large quadrupole content (>85%) in the 2–2 transition. The present investigation of this correlation confirms these spin assignments and shows the 0.65 transition to be almost pure $E2$ (<1% $M1$). The 1.40–1.20 and 2.05–0.55 correlations are consistent with a spin value of 3+ for the 2.60-Mev level, with the 1.40-Mev gamma ray being pure $M1$ and the 2.05-Mev transition being a mixture of 95% $E2$ and 5% $M1$.

* Supported in part by the Michigan Memorial Phoenix Project and in part by the Office of Naval Research.
[1] J. J. Kraushaar and M. Goldhaber, Phys. Rev. **89**, 1081 (1953).
[2] F. R. Metzger and W. B. Todd, J. Franklin Inst. **256**, 277 (1953).

**F2. Radiations from $Tb^{156}$. I.*** L. T. Dillman, R. W. Henry, N. B. Gove, and R. A. Becker, *University of Illinois.*—Terbium oxide was irradiated with bremsstrahlung of maximum energy 240 Mev. Studies with a scintillation spectrometer, involving a 100-channel analyzer, yielded gamma-ray energies (in kev) 88, 130, 200, 250, 340, 540, 620, 1210, and 1410. There were indications of weak radiation of still other energies. Comparison of these results, together with the presence of half-lives of 5.5 hours and 5.2 days, with other published data[1] indicated the activity to be associated with $Tb^{156}$. Beta-gamma coincidence data with the 5-day activity indicate that the 200-, 540-, 1210-, and 1410-kev gamma rays follow $\beta^-$ emission. The possibility of gamma radiation of lower energy is being further investigated. At least three $\beta^-$ groups have been found leading to excited states of the daughter nucleus. The absence of coincidences involving the 88-kev transition confirm the reported[2] assignment of this to an isomeric state in $Tb^{156}$.

* This work was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] T. H. Handley and W. S. Lyon, Phys. Rev. **99**, 1415 (1955).
[2] J. W. Mihelich and B. Harmatz, Phys. Rev. **106**, 1232 (1957).

**F3. Radiations from $Tb^{156}$. II.*†** R. W. Henry, L. T. Dillman, N. B. Gove, and R. A. Becker, *University of Illinois.*—Detailed studies of gamma-gamma coincidences in the 5-day activity confirm the grouping of the 200-, 540-, 1210-, and 1410-kev gamma rays together, reported in the previous abstract as following $\beta^-$ decay. Similar studies associate the 130-, 250-, 340-, and 620-kev radiations together. Further, these display strong coincidences with x-rays. Hence this second group is designated as following orbital capture. Indications are that radiation of much higher energy is also involved on the orbital capture side. Incomplete coincidence studies of the 5-hour activity indicate positrons to be present. These do not accompany the longer-lived activity. A level scheme will be presented.

* This work was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
† See, also, the previous abstract.

**F4. Isomers in $Tb^{158}$ and $Ho^{162}$.*** N. B. Gove, L. T. Dillman, R. W. Henry, and R. A. Becker, *University of Illinois.*—These isomers, reported by Hammer and Stewart,[1] have been further studied with NaI crystals, proportional counter, and an RIDL 100-channel analyzer. $Tb^{158}$ and $Ho^{162}$ were produced by $(\gamma,n)$ and $(\gamma,2n)$ reactions, respectively, on the stable isotopes, using x-rays from the Illinois 22-Mev betatron. A pneumatic tube was used to transfer the source from betatron to the detector. For the 10.5-second $Tb^{158}$ isomer the $\gamma$ ray was observed to be 111±2 kev. X-rays present were confirmed to be those of Tb by comparison with x-rays of Hf, Sm, and Gd, employing a proportional counter. By comparison of the $\gamma$ ray with the Tb x-ray the $K$-conversion coefficient was found, after correction for fluorescence yield, detector efficiency, and self-absorption in the metallic sources, to be 61±9. This together with the half-life, favors an $M3$ assignment to the transition. For the 0.8-second $Ho^{162}$ isomer the $\gamma$-ray energy, as given by Hammer and Stewart, is 305 kev. We find the $K$-conversion coefficient to be 0.19±0.06, indicating an $E3$ transition. These results are consistent with the theories of Gottfried[2] and Nilsson.[3]

* This work was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] C. L. Hammer and M. G. Stewart, Phys. Rev. **106**, 1091 (1957).
[2] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).
[3] Kurt Gottfried, Phys. Rev. **103**, 1017 (1956).

**F5. Electron Capture of $H^{f173}$ to Levels in $Lu^{173}$.*** T. J. Ward and J. W. Mihelich, *University of Notre Dame,* and B. Harmatz and T. H. Handley, *Oak Ridge National Laboratory.*—A source of $Hf^{173}$ was extracted from Lu which had been bombarded with protons in the ORNL 86-inch cyclotron. The gamma-ray and internal conversion electron spectra have been examined. Gamma-ray transitions of 123($E1$), 135($M1+E2$), 140($E1$ or $M1+E2$), 162($M1+E2$), 297, 307, 312, 542, and 552 kev are observed.[1] The transitions of 135 and 162 kev, which are in prompt coincidence, may form a rotational band with a 297-kev crossover. The energy ratio of 2.2 for the second to first excited states is in agreement with a spin sequence of 7/2, 9/2, 11/2. The ground-state spin of $Lu^{173}$ as obtained from a Nilsson diagram is either $5/2^+$ or $7/2^+$. The 123-kev transition does not appear to be in prompt coincidence with any photon of energy greater than 50 kev; accordingly, excluding the unlikely probability of $L$-capture, it is likely that a metastable level ($T_{\frac{1}{2}}\sim$many microseconds) exists at 123-kev. The comparative half-life of such a transition shows a retardation factor of $10^8$ as compared to single particle estimate. Delayed coincidences corresponding to a half-life of $\sim 10^{-7}$ second were observed between $K$ x-rays and the 140-kev photons.

* Supported by the U. S. Atomic Energy Commission.
[1] Mihelich, Harmatz, and Handley, Phys. Rev. (to be published).
[2] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 16 (1955).

**F6. Decay of $Gd^{161}$.*** L. C. Schmid, S. B. Burson, *Argonne National Laboratory,* and J. M. Cork, *University of Michigan.*— $_{64}Gd^{161}$ (3.73-min) was produced by neutron irradiation of enriched gadolinium oxide (95.4% $Gd^{160}$) in the Argonne reactor (CP5). This decay is characterized by $\beta^-$ emission to several excited states in $_{65}Tb^{161}$. From a study of the radiations, the existence of five excited states is deduced. These have energies of 56.8, 315.5, 417.5, 481.7, and 582.8 kev. There is also evidence for a level at about 135 kev. Eleven transitions were observed. Internal-conversion-electron groups representing eight of these were measured using magnetic spectrographs. These transitions have energies of 56.8±0.2, 102.0±0.4, 166.2±0.6, 180.8±0.3, 267.3±0.8, 283.9±0.4, 315.5±0.5, and 360.8±0.5 kev. These eight, as well as transitions of 78±2, 482±5, and 526±5 kev, were detected by scintillation methods. The transitions are fitted into a consistent decay scheme by means of coincidence measurements using the Argonne 256-channel scintillation spectrometer.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

## *Invited Papers*

**F7. Electron Polarization and Beta Decay.** T. A. Pond, *Washington University.* (20 min.)
**F8. Angular Correlation of Annihilation Radiation.** W. E. Millett, *University of Texas.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Wayman Crow, 101

(J. W. McCLURE presiding)

## *Liquids and Solids*

**G1. X-Ray Diffraction in Liquid Sulfur.** CLIFFORD TOMPSON AND N. S. GINGRICH, *University of Missouri.*—Experimental results in the determination of the x-ray diffraction patterns of liquid sulfur[1-4] at different temperatures do not agree with each other in a number of respects and the present investigation was undertaken with improved technique in an attempt to resolve the differences. Improved source of x-rays, monochromatization, lining up, and especially detection using a scintillation head provide means to obtain considerably more detail in the diffraction patterns. Initial runs confirm in some respects the results of Prins[4] regarding the shapes and positions of the main peaks at different temperatures. An intensive study is being made to obtain diffraction patterns to as large a scattering angle as possible so that they can be prepared for Fourier analyses to give atomic distribution curves.

[1] A. H. Blatchford, Proc. Phys. Soc. (London) **45**, 493 (1933).
[2] J. A. Prins, Trans. Faraday Soc. **33**, 189 (1937).
[3] N. S. Gingrich, J. Chem. Phys. **8**, 29 (1940).
[4] J. A. Prins, Physica **20**, 124 (1954).

**G2. Devitrification in Aqueous Solutions.** B. LUIET AND G. RAPATZ, *American Foundation for Biological Research.*—When aqueous solutions of crystalloids, such as sodium chloride or glucose, or of colloids, such as gelatin, are cooled very rapidly, they solidify in a vitreous mass, which devitrifies upon being rewarmed. According to the generally accepted views, devitrification consists either in the growth of pre-existing microcrystals in "cryptocrystalline" structures, or in the formation of new crystals in "truly vitreous" material. Our observations, made either directly under the microscope or after recording on moving picture films, point to a new aspect of the mechanism. Devitrification, as indicated by the appearance, upon warming, of a cloud of submicroscopic particles, takes place only *within* "crystallization units" (dendrites) which have grown to microscopic or macroscopic dimensions from single nuclei, during the cooling process. Material *outside* of these units does not devitrify. Devitrification appears, thus, as a second crystallization occurring in the interstices left unoccupied, within the dendrites, by the needles which grew radially from single centers, and by their branches, in a first crystallization. We have no information yet on the mode of action of the first crystallization (into dendrites) in bringing about the second (into submicroscopic particles, *within* the dendrites).

**G3. Sapphire ($a$-$Al_2O_3$) Microcrystals.** W. W. WEBB AND W. D. FORGENG, *Union Carbide Corporation.*—Small euhedral crystals of $a-Al_2O_3$ (sapphire) were produced by the oxidation of aluminum and an aluminum alloy in wet hydrogen between 1300 and 1450°C. These crystals were up to 10 mm long in the form of tapered hexagonal needles from 1 to 50 $\mu$ thick and blade-shaped platelets from 0.5 to 10 $\mu$ thick. The growth process appears to involve mass transport of AlO vapor and subsequent formation of $Al_2O_3$ on the crystal surface. Rapid growth occurs on the tips of needles and the edges of platelets at lattice steps formed by the intersection of screw dislocations with these surfaces. These screw dislocations were characterized by capillary holes along their axes. Growth hillocks that may not have been associated with screw dislocations were observed on (00.1) surfaces. The sapphire needles or whiskers could be elastically deformed in bending to strains greater than 2% before failure by brittle fracture occurred. These strains correspond to a bend strength of $\sim 10^{11}$ dyne cm$^{-2}$.

**G4. Detection of Screw Dislocations in $a$-$Al_2O_3$ Whiskers.** R. D. DRAGSDORF* AND W. W. WEBB, *Union Carbide Corporation.*—An improved x-ray method has been worked out in detail for the observation and measurement of the lattice twist due to screw dislocations in cylindrical whiskers. Measurements of the tilt of equatorial Laue spots recorded on film in a cylindrical camera utilizing continuous x-rays from a microfocus source provide sufficient sensitivity to detect twists only 0.01 of the calculated value for prime axial screw dislocation in a whisker 1 micron in radius. Simple but effective precautions were devised to prevent plastic deformation during handling and motion during exposure. Nine $a-Al_2O_3$ whiskers with ⟨00.1⟩ growth axes described by Webb and Forgeng in the preceding abstract were examined. Measurements of the tilt of equatorial Laue spots and the size of each of the whiskers were used to compute the Burgers vector of the axial screw dislocations. In every case the Burgers vector was a multiple of the $c$ axis unit cell dimension, 13 A. The position of the dislocation was clearly shown by a capillary hole along the core, and the magnitude of the lattice twist was checked by optical observations of the twist of the hexagonal facets of the whiskers.

* Present address: Kansas State College.

**G5. Effect of Lattice Compressibility on Orientational Transitions in Molecular Crystals.** HUBERT M. JAMES, *Purdue University.*—Since orientational coupling between molecules in crystals must depend on the lattice spacings, there must also exist corresponding radial forces between molecules that depend on molecular orientation. Molecular ordering in a crystal thus produces lattice deformations that in turn tend to stabilize one type of order with respect to another. The effect of orientation-dependent radial couplings on orientational transitions in solid methane has been worked out in detail, treating the molecules as rigid spherical rotators with orientational coupling due to interaction of charge distributions having tetrahedral symmetry. Previously reported calculations of Keenan and James using this model, but neglecting lattice compressibility, predict existence of two orientational transitions, as observed in $CD_4$. Lattice compressibility shifts both transition temperatures upward, and changes the upper transition from second to first order. (Because of hysteresis effects, either result is compatible with observation.) It raises the computed integrated heat of the upper transition into better agreement with observations on $CD_4$, and predicts volume changes in good agreement with those observed in $CH_4$. The theory indicates that the phase of $CD_4$ stable at the lowest temperatures will have tetragonal symmetry, with the $c$ axis about 1% shorter than the $a$ axis.

**G6. Optical Absorption and Photoemission of Barium and Strontium Oxides, Sulfides, Selenides, and Tellurides.** R. J. ZOLLWEG, *Westinghouse Research Laboratories.*—Thin films of barium and strontium salts of the NaCl crystal type have been prepared in sealed-off quartz and Corning 9741 glass tubes. Optical absorption measurements show a doublet at the onset of the strong ultraviolet absorption similar to that observed with BaO[1] plus additional structure toward higher photon energy. Most of this structure is presumably associated

with the creation of exciton states. The splitting of the initial doublet is less for BaS (0.15 ev) than for BaO (0.24 ev), but is greater for the selenides (0.35 for BaSe) and tellurides (0.54 ev for BaTe). A second doublet appears in the case of BaS with the same splitting as the first, suggesting that it may be associated with excitation of an anion electron to its space-diagonal cation. Three additional absorption peaks are observed in BaSe and BaTe. In SrO and SrS the initial doublet is only partially resolved and the additional structure is less pronounced in all the strontium salts. Photoemission measurements from these films determine an upper limit to the band gap assuming the bottom of the conduction band to be at or below the vacuum level.

[1] R. J. Zollweg, Phys. Rev. **97**, 288 (1955).

**G7. Photoemission from Alkali-Antimony Compounds.** W. E. SPICER, *RCA Laboratories.*—A theoretical model is proposed to explain the observed photoemission from $Rb_3Sb$, $Cs_3Sb$, $(NaK)_3Sb$, $[(Rb)NaK]_3Sb$, and $[(Cs)NaK]_3Sb$. In the region of relatively high yield where the emission is due to excitation of valence band electrons, an expression is obtained which may be fitted quite well to the experimental data by using the following assumptions: a parabolic valence band, a density of states above the vacuum level in the conduction band which is independent of energy, a predominance of indirect transitions, and an escape probability which decreases exponentially with distance from the surface. In the threshold region where the experimental data do not fit the above model, measurements at 300°K and 77°K indicate that the threshold response is due to an exponential distribution of acceptor states.

**G8. Theory of the Dielectric Constants of Alkali Halides.** B. G. DICK, JR.,† AND A. W. OVERHAUSER, *Cornell University.*—The simple classical theories of the dielectric constants and compressibility of ionic crystals lead to two relations among experimental quantities from which arbitrary parameters have been eliminated, the Szigeti relations. Neither is satisfied by the data, indicating the inadequacy of these simple theories. The short-range repulsive interaction between ions with closed shell electron configurations is investigated and an approximate interpretation of the Born-Mayer potential in terms of overlap integrals is developed. These results are applied to the interaction of model ions consisting of rigid charged shells bound to cores by harmonic restoring forces. Using this model, polarization mechanisms neglected in the simple dielectric constant theory, the "short-range interaction polarization" and the "exchange charge polarization," are described. Both arise from charge redistributions occuring when the ions move with resulting changes in electron overlaps. Incorporated into a crystal these ion models permit the derivation of generalizations of the Szigeti, Clausius-Mossotti, and Lorenz-Lorentz relations. The $e^*/e$ of the second Szigeti relation can then be calculated and comparison with the $e^*/e$ values derived from experimental data imply that the above polarization mechanisms must be at least in part responsible for the deviation of this parameter from unity.

† Present address: University of Illinois.

**G9. Fundamental Optical Absorption of Some IIA-VIB Compounds.*** G. A. SAUM AND E. B. HENSLEY, *University of Missouri.*—The IIA-VIB compounds may be regarded as the divalent equivalents of the alkali halides. The fundamental optical absorption spectra between quantum energies of 2.5 and 5.6 ev have been measured on thin films of the oxides, sulfides, selenides, and tellurides of barium and strontium and on the selenides and tellurides of calcium and magnesium. Films were prepared in a vacuum by evaporating the two desired elements onto a quartz substrate and then heating to cause chemical reaction. Successive heatings were performed to anneal the films. Optical absorption measurements were made before and after annealing, and at both room temperature and liquid air temperature. Both annealing and lowering the measuring temperature sharpened the observed absorption peaks. For each compound studied, two or three absorption peaks were observed in the near ultraviolet which were interpreted as exciton peaks. The position of the absorption peaks for the compounds was found to shift to the ultraviolet for lighter elements in either the IIA or VIB group. This is similar to the behavior observed for the alkali halides.

* Supported in part by the Office of Naval Research.

**G10. Debye Loss in Calcium- and Lead-Doped Sodium Chloride.** J. PASTERNAK, *U. S. Naval Research Laboratory.*—Dielectric loss measurements at several frequencies have been carried out as a function of temperature over the range of 30°C to 150°C for lead-doped and calcium-doped sodium chloride. The height of the loss peak for each impurity was found to rise with increasing temperature. Activation energies for "rotation" of the impurity-vacancy pairs were found to be 0.65 ev for calcium-doped sodium chloride and 0.67 ev for lead-doped sodium chloride. In the absence of clusters, the peak heights, being proportional to the concentration of the impurity-vacancy pairs, would be expected to decrease with increasing temperature because of impurity-vacancy pair dissociation. The increase in impurity-vacancy pairs with increasing temperature, as indicated by the data, is attributed to clusters of impurities and vacancies which dissociate into impurity-vacancy pairs as the temperature increases.[1] The ionic conductivity due to free vacancies is strongly structure sensitive over the range of temperatures used in these experiments so it was not possible to obtain information about the concentration of free positive ion vacancies. Similar measurements on other divalent metal impurities in sodium chloride and divalent metal impurities in potassium chloride are in progress.

[1] Burstein, Oberly, Henvis, and Davisson, Phys. Rev. **81**, 459–460 (1951).

**G11. Symmetry of the H Center in KCl and KBr.** W. DALE COMPTON AND CLIFFORD C. KLICK, *U. S. Naval Research Laboratory.*—Duerig and Markham[1] have reported that only two prominent absorption bands are produced by x-irradiation of KCl, NaCl, and KBr at temperatures near 4°K. These are the *F* band and a shorter wavelength band called the *H* band. Some of the symmetry properties of color centers can be determined by studying the dichroic absorption produced by irradiation with polarized light that is absorbed by the center. This has been done for the *H* centers in KCl and KBr. Some of the results are: 1. The *H* center in KCl and KBr is anisotropic. The optical dipole is oriented parallel to [011]. 2. *H* centers in KBr that are initially oriented at random can be reoriented by irradiating with polarized light. That is, centers whose dipoles absorb light polarized along [011] are reoriented such that their dipoles become parallel to [011]. 3. The oscillator strength of the *H* band in KBr is approximately 0.5 that of the *F* center. Seitz[2] tentatively proposed that the *H* center was a hole trapped at a pair of positive and negative ion vacancies. This model does not satisfy the observed [011] symmetry of the center.

[1] W. H. Duerig and J. J. Markham, Phys. Rev. **88**, 1043 (1953).
[2] F. Seitz, Revs. Modern Phys. **26**, 7 (1954).

***Invited Paper***

**G12. Polarized Light and Electron-Spin Measurements in Irradiated Alkali-Halide Crystals.** C. J. DELBECQ, *Argonne National Laboratory.* (30 min.)

FRIDAY AFTERNOON AT 2:15

Louderman Auditorium

(R. E. NORBERG presiding)

## *Radio-Frequency Spectroscopy*

**H1. Hyperfine Structure of $Au^{194}$.*** W. M. HOOKE, R. L. CHRISTENSEN, D. R. HAMILTON, J. B. REYNOLDS,† AND H. H. STROKE,‡ *Princeton University.*—The previously reported hyperfine transition[1] ($I=1$, $J=1/2$, $\Delta F=0$) of 40-hr $Au^{194}$ has been studied using the atomic beam resonance method. The rotating disk, flop-out technique[2] was used; the methods of source preparation and beam detection have already been described.[1] Resonances were observed at 6 different values of the transition magnetic field. These measurements yielded $\Delta\nu=3600\pm120$ mc/sec, corresponding to an absolute value of the magnetic moment of $0.068\pm0.007$ nm.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Now at Washington University.
‡ Now at M.I.T.
[1] Reynolds, Christensen, Hooke, Hamilton, Stroke, Ewbank, Nierenberg, Shugart, and Silsbee, Bull. Am. Phys. Soc. Ser. II, **2**, 317 (1957).
[2] Christensen, Bennewitz, Hamilton, Reynolds, and Stroke, Phys. Rev. **107**, 633 (1957).

**H2. Spin of $Br^{83}$.*** H. L. GARVIN, T. M. GREEN, AND E. LIPWORTH, *University of California, Berkeley.*—The spin of $Br^{83}$ has been measured by an atomic beam "flop-in" experiment. Spin resonances have been obtained at three values of magnetic field. The active material was supplied by Oak Ridge in the form of KBr powder and elemental bromine was obtained by a chemical separation. The bromine was placed in a glass vial attached to a slow leak leading to a quartz discharge tube in the apparatus oven chamber; a 450-kc rf discharge in the tube produced a high degree of dissociation in the beam. Silver-coated buttons were used to collect the beam, and the $Br^{82}$ was detected by counting radioactive decays in low-background $\beta$ counters. The measurements indicate a value of 5 for the spin of $Br^{83}$. Preliminary results indicate that the quadrupole interaction is sufficiently large to cause the separation of $F=13/2$, $F=11/2$ levels to be substantially less than that of the $F_{11/2}$, $F_{9/2}$ levels.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**H3. Nuclear Spin of $I^{128}$.** J. E. SHERWOOD, *Oak Ridge National Laboratory.*—The atomic beam magnetic resonance technique has been used to measure the nuclear spin of 25-min $I^{128}$. A value of 1 was obtained, thus confirming the prediction of Benczer *et al.*[1] The degree of molecular dissociation was enhanced by superheating the iodine vapor and detection was accomplished by deposition with subsequent counting with a scintillation counter. The radio-frequency spectrum was observed in the stray field (about 2.5 gauss) of the deflecting magnets. The equipment was calibrated by means of a beam of potassium atoms. The technical assistance of Mr. John M. Winter is gratefully acknowledged.

[1] Benczer, Farrelly, Koerts, and Wu, Phys. Rev. **101**, 1027 (1956).

**H4. Power Sharpening of Molecular Beams Resonance Lines.*** E. COMMINS, *Columbia University,* AND R. NOVICK, *University of Illinois.*—The two level molecular beams resonance line shape predicted by Rabi exhibits a central peak and several side peaks of rapidly decreasing amplitude. The width and amplitude of the central peak both decrease as the oscillating magnetic field ($H$) is increased from its optimum value ($H_0$) to twice $H_0$. A twofold reduction in width and a tenfold reduction in amplitude occur when $H=1.8H_0$. As $H$ approaches $2H_0$ the amplitude decreases as the fourth power of the width. In the case of normal molecular beams experiments the thermal velocity distribution serves to smear out the structure, and the observed resonance consists of a single peak whose width increases monotonically as $H$ is increased. In the normal case a reduction in width is observed when $H$ is reduced below $H_0$. This results from a quasi-velocity selection and is distinct from the present effect. The monoenergetic nature of the beam employed in the recent experimental determination[1] of the hyperfine structure of the $2^3S_{1/2}$ state of ionized $He^3$ has permitted observation of the structure and power sharpening effect discussed above. An 18% reduction in width and a 36% reduction in intensity of the central peak were observed when $H=1.55H_0$. These values differ slightly from those predicted from Rabi's formula; the difference is believed to result from inhomogeneities in the oscillating field employed in the experiment.

* Supported by the Office of Naval Research, The Signal Corps, and the National Science Foundation.
[1] R. Novick and E. Commins, Phys. Rev. **103**, 1897 (1956).

**H5. Double Pulse Nuclear Resonance in Solids.*** I. J. LOWE,† *Washington University.*—The general formula describing a free induction decay[1] following one rf pulse has been extended by the insertion of the proper rotation operators to the description of the shape of the free induction signal following two rf pulses separated by time $\tau$. For the case of a rigid solid made up of one magnetically active nuclear species, the formula predicts that a 90°, 180° pulse sequence should produce a free induction signal identical to that for a single 90° pulse and that a 90°, 90° pulse sequence should produce a free induction signal different from that for a single 90° pulse. Experimentally, a "solid echo" is observed to follow the 90°, 90° pulse sequence in all rigid solids examined. For a rigid solid made up of two magnetically active nuclear species $A$ and $B$, the formula predicts that the free induction signal following a $90°_A$, $180°_A$ pulse sequence should be different from the free induction signal following a $90°_A$ pulse, and should be identical to the free induction signal following a $90°_A$, $180°_B$ pulse sequence. A "solid echo" has been observed to follow a $90°_F$, $180°_F$ pulse sequence in LiF and $NH_4F$.

* Supported in part by the U. S. Air Force Office of Scientific Research.
† Alfred P. Sloan Foundation Post-Doctoral Fellow.
[1] I. J. Lowe and R. E. Norberg, Phys. Rev. **107**, 46 (1957).

**H6. Nuclear Magnetic Resonance in Pile-Irradiated LiI.*** JOHN F. HON† AND P. J. BRAY, *Brown University.*—Using a Pound-Watkins type recording spectrometer the magnetic resonance lines of $Li^7$ and $I^{127}$ in a single crystal of LiI irradiated in the Brookhaven reactor (total integrated flux of $4.1\times10^{18}$ nvt) have been compared with the same lines in an unirradiated crystal. The lines observed in the irradiated crystal have a lower intensity than the lines in the unirradiated crystal. From the decrease of intensity of the $Li^7$ line the number of defects (vacancies plus interstitials) present is estimated to be $1.1\times10^{-2}$ defect/atom and from the intensity decrease of the $I^{127}$ line the number is $2.86\times10^{-3}$ defect/atom, assuming the defects to be introduced at random into the crystal. The difference in these two results can be explained on the basis that the number of resonating nuclei affected by a defect is different in the two cases and that the defects are

not introduced at random. The observed defect density is about 1/30 of that predicted with the methods of Seitz and Koehler.[1] Some degree of annealing is probable.

* Work supported by the U. S. Atomic Energy Commission.
† Now at Atomics International.
[1] F. Seitz and J. S. Koehler in *Solid State Physics* (Academic Press, Inc., New York, 1956), Vol. II.

**H7. Pure Quadrupole Resonance Studies of Nitrogen-Containing Heterocyclics.** R. G. BARNES,* *Iowa State College*, AND P. J. BRAY,† *Brown University*.—Studies of the effect of substituents on the electron distribution on chlorobenzene[1] have been extended to substituted quinone and heterocyclics containing nitrogen in the ring. $Cl^{35}$ and $Br^{81}$ resonance frequencies yield[1] the effective sigma value of the quinone oxygens and heterocyclic ring nitrogens at the carbons to which the halogens are attached. Jaffe's relation[2] between sigma value and charge distribution is used to determine the latter. The charge distributions obtained in this manner agree well with calculated[2,3] values in quinone and pyridine. Agreement is poor for quinoline. The effect of a ring nitrogen on the double bond character of carbon-halogen bonds immediately adjacent to the nitrogen is measured quantitatively through the dependence[4] of the experimental coupling constant on the double bond character. The effect is easily measured since it lowers the halogen resonance frequency by 3% or more.

* Work performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
† Supported by a grant from the National Science Foundation.
[1] P. J. Bray and R. G. Barnes, J. Chem. Phys. **27**, 551 (1957).
[2] H. H. Jaffe, J. Chem. Phys. **20**, 1554 (1952).
[3] C. A. Coulson, *Valence* (Oxford University Press, New York, 1953), p. 256.
[4] R. Bersohn, J. Chem. Phys. **22**, 2078 (1954).

**H8. Nuclear Quadrupole Coupling Constants of $Li^7$ in Lithium Compounds.** P. J. BRAY AND J. F. HON,* *Brown University*.—Nuclear magnetic resonance studies of the $Li^7$ quadrupole coupling constant have previously been made in lithium carbonate powder[1] and single crystals of lithium sulfate[1,2] and spodumene.[3] The present work is concerned with powders. The splittings in powdered spodumene have been observed and used, with single crystal data,[3] to check the first-order line shape theory[4] when the asymmetry parameter is not zero. Gamma irradiation has been used to shorten $T_1$ and reduce saturation effects in such compounds[1] as $LiNO_3$ so that the quadrupolar splittings are measurable. The results will be reported for $LiNO_3$, $LiNO_3 \cdot 3H_2O$, LiOH, $LiOH \cdot H_2O$, $LiIO_3$, $Li_3PO_4$, $LiTiO_3$, and $LiZrO_3$. No splittings have been found in $Li_2C_2O_4$, $Li_2SiO_3$, and $LiBH_4$. Discussion of the observed coupling constants and asymmetry parameters will concern crystal structure and symmetry.

* Now at Atomics International.
† Work supported by the U. S. Atomic Energy Commission and by a grant from the National Science Foundation.
[1] R. V. Pound, Phys. Rev. **79**, 685 (1950).
[2] E. Hirahara and M. Murakami, J. Phys. Soc. (Japan) **11**, 608 (1956).
[3] Volkoff, Petch, and Smellie, Can. J. Phys. **30**, 270 (1952).
[4] M. Cohen and F. Reif in *Solid State Physics* (Academic Press, Inc., New York, 1957), Vol. 4.

**H9. $B^{11}$ Nuclear Magnetic Resonance in Planar Hexagonal Compounds.*** A. H. SILVER† AND P. J. BRAY, *Brown University*.—The $B^{11}$ nmr has been recorded at 7.177 Mcps in powdered $TiB_2$, $ZrB_2$, and BN. Isomorphous $TiB_2$ and $ZrB_2$ have symmetric three line patterns due to first-order quadrupole perturbation. In BN the signal is very weak and the resonance line is broad and asymmetric about the Larmor frequency of $B^{11}$. This is due to a second-order quadrupole interaction. The reported structures[1] of $TiB_2$ and $ZrB_2$ place the boron atoms in planar hexagonal sheets. BN has a graphite-like structure[2] with alternating boron and nitrogen atoms. Because of the threefold symmetry in each material, the asymmetry parameter $\eta$ vanishes. Based on the observed splittings the quadrupole coupling constants are calculated as follows: $TiB_2$, $eqQ = 180 \pm 6$ kcps; $ZrB_2$, $eqQ = 118 \pm 6$ kcps; BN, $eqQ = 2.96 \pm 0.2$ Mcps. The values of $eqQ$ will be used to infer probable bonding electron configurations.

* Research supported by U. S. Atomic Energy Commission.
† Present address: Scientific Laboratory, Ford Motor Company.
[1] R. Kiessling, Acta Chem. Scand. **4**, 209 (1950).
[2] R. S. Pease, Acta Cryst. **5**, 356 (1952).

**H10. Magnetic Resonance Line Shapes in Diluted Substances with Inhomogeneous Broadening.** P. W. ANDERSON, *Bell Telephone Laboratories*.—The Markoff method has been used in various guises[1,2] to approximate magnetic resonance line shapes. When the broadening is inhomogeneous, the method is exact. The correct expression for the Fourier transform $\varphi(t)$ of the line shape has been given only for concentrated substances[2] and for the very dilute, quasi-continuous case.[1] The expression for randomly diluted samples is

$$\varphi(t) = \Pi_j (1 - f + f \cos B_{ij} t). \qquad (1)$$

Here $f$ is the fractional concentration, the product is over-all sites $j$ neighboring to a given radiating spin $i$, and $B_{ij}$ is the interaction (defined as in Lowe and Norberg[2]). (1) would be expected to apply directly in such problems as Cu broadened by Mn in Cu Mn and donors in Si broadened by $Si^{29}$. We discuss the occurrence of Lowe-Norberg oscillations in (1), and their physical meaning.

[1] P. W. Anderson, Phys. Rev. **82**, 342 (1951).
[2] I. Lowe and R. G. Norberg, Phys. Rev. **107**, 46 (1957).

**H11. Electron Spin Resonance of $Mn^{3+}$ in Germanium.** GEORGE D. WATKINS, *General Electric Research Laboratory*.—The electron spin resonance of $Mn^{3+}$ has been observed in germanium at 77°K and 1.5°K. The spectrum indicates that the $Mn^{3+}$ ions are in a ${}^5S_{5/2}$ state with $g = 2.0061 \pm 0.0002$. The hyperfine constant $A$ is $-45.6 \pm 0.3$ gauss, and there is a small cubic term $a = +9.5 \mp 0.5$ gauss. This is consistent with the model[1] that manganese enters substitutionally and that it accepts two electrons into the $4s4p$ shell, leaving the $3d$ shell relatively unaffected. The absence of noncubic terms indicates that no defect is nearby. The individual lines of the spectrum do not appear to have the characteristic shape that would arise from hyperfine interaction with 8% abundant $Ge^{73}$. As a result, a tentative upper limit of 5% can be estimated for the $3d$ charge transfer to the four nearest neighbors. This is no more than occurs for $Mn^{2+}$ in ionic environments. The low magnitude of $A$ probably has its origin then in the increased promotion energy to the antibonding $4s$ state as suggested by Van Wieringen.[2]

[1] W. W. Tyler and H. H. Woodbury, Phys. Rev. **102**, 647 (1956).
[2] J. S. Van Wieringen, Disc. Faraday Soc. No. 19, 119 (1955).

**H12. Cyclotron Absorption in Antimony.*** W. R. DATARS† AND R. N. DEXTER,‡ *University of Wisconsin*.—Microwave experiments similar to those on Bi have been performed on very pure Sb crystals using linearly and circularly polarized radiation at 23 000 Mcps and operating at liquid helium temperatures. The absorption derivative showed peaks identified with electron and hole resonances. When corrected for shift of resonance peak due to scattering with $\omega\tau = 2$ the following cyclotron masses were found for electrons using linearly polarized $E_{rf}$ perpendicular to $B$ and in the trigonal plane; with $B$ parallel to bisectrix and surface $m^* = 0.065m_0$, $0.125m_0$, with $B$ parallel to binary axis and surface $m^* = 0.073m_0$ and an unresolved high mass peak. Results with other orientations of $B$, circular polarization data and attempts to see Azbel'-Kaner effects will be described. The components of the mass tensor for electrons appear to be in good agreement with Shoenberg's mass values[1] for tilted ellipsoids in momentum space. The holes appear to lie on one ellipsoid of revolution with axis of revolution along the trigonal direction and

having $m_1 = m_2 = 0.021 m_0$ and $m_3 = 0.032 m_0$ where $m_0$ is the mass of the free electron.

* Supported by the Alfred P. Sloan Foundation Inc., the Wisconsin Alumni Research Foundation, and the Brittingham Trust Fund.
† Ontario Research Foundation Scholar.
‡ Alfred P. Sloan Fellow.
[1] D. Shoenberg, Trans. Roy. Soc. (London) **245**, 1 (1952).

**H13. Line Intensities in Vibration-Rotation Bands of Diatomic Molecules.** Robert Herman, Richard W. Rothery,* AND ROBERT J. RUBIN,† *General Motors Corporation.*—The influence of vibration-rotation interaction on line intensities in molecular spectra of diatomic molecules has been determined for the anharmonic oscillator[1] and the Morse oscillator.[2] The results of the latter treatment have now been simplified considerably for numerical calculation. The $F$ factor which expresses the rotational dependence of the vibrational matrix element has been calculated for the 1-0, 2-0, 3-0, and 21-vibration-rotation bands of HF, HCl, and CO. The $F$ factors calculated for the fundamental bands using the two models mentioned above are in excellent agreement. A general expanded formula for any band of a rotating Morse or Pekeris oscillator as well as the above numerical results will be discussed.

* Visiting Member of Research Staff from Wayne State University.
† Visiting Consultant now at National Bureau of Standards.
[1] R. Herman and R. F. Wallis, J. Chem. Phys. **23**, 637 (1955).
[2] R. Herman and R. J. Rubin, Astrophys. J. **121**, 533 (1955).

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FRIDAY AFTERNOON AT 2:15

Brown Auditorium

(F. W. LOOMIS presiding)

### *Symposium on Superconductivity*

**J1. A Theory of Superconductivity.** JOHN BARDEEN, *University of Illinois.* (40 min.)
**J2. Evidence for an Energy Gap in Superconductors from Microwave Absorption.** M. P. GARFUNKEL, *Westinghouse Research Laboratory.* (30 min.)
**J3. Ultrasonic Attenuation in Superconductors.** R. W. MORSE, *Brown University.* (30 min.)
**J4. Nuclear Relaxation in Superconductors.** C. P. SLICHTER, *University of Illinois.* (30 min.)

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FRIDAY EVENING AT 7:30

CORONADO Hotel

(H. D. SMYTH presiding)

### *Banquet of the American Physical Society*

After-dinner speakers: E. U. CONDON, A. H. COMPTON, and J. P. HAGEN

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SATURDAY MORNING AT 9:30

Brown Auditorium

(V. JACOBSMEYER presiding)

### *Semiconductors and Insulators*

**L1. Dipole Scattering in Semiconductors.*** ROBERT R. SLOCUM, *Michigan State University.*—Recent work on semiconductors[1] suggested consideration of dipole scattering effects in these substances. Using a formulation due to Mott for scattering centers of polar symmetry the cross section for dipole scatterers was calculated, and subsequently a relaxation time obtained. Comparison of this relaxation time with that of Conwell and Weisskopf[2] for ionized impurities and that for neutral impurities[3] showed that over all temperature ranges the dipole scattering is negligible with respect to both. The relaxation time for the dipole scattering process exhibits a $T^{\frac{1}{2}}$ dependence on temperature.

* Supported in part by the U. S. Air Force Office of Scientific Research of the Air Research and Development Command.
[1] Reiss, Fuller, and Morin, Bell System Tech. J. **35**, 535 (1956).
[2] E. M. Conwell and V. F. Weisskopf, Phys. Rev. **77**, 388 (1950).
[3] C. Erginsoy, Phys. Rev. **79**, 1013 (1950).

**L2. Effect of Heat Treatment on the Electrical Properties of Indium Arsenide.** J. R. DIXON AND D. P. ENRIGHT, *Naval Ordnance Laboratory.*—The effect of heat treatment on the

carrier lifetime, carrier concentration, and Hall mobility in indium arsenide has been investigated. $n$- and $p$-type samples have been subjected to various quenching and annealing procedures from elevated temperatures ranging downward from 900°C. The carrier lifetime measured by the photoelectromagnetic-photoconductive ratio method as applied to indium arsenide[1] is found to increase after annealing and to decrease as a result of quenching. Changes in carrier lifetimes of more than a factor of ten have been produced by alternately quenching and annealing. Large variations in the carrier concentration and Hall mobility have been observed as a result of heat treatment. For example, the carrier concentrations increased by approximately $2\times10^{16}$ cm$^{-3}$ in $n$-type indium arsenide which was heated for three hours at 850°C and then quenched. Successive quenches of this type have produced increases of more than a factor of $10^2$ in carrier concentration and increases of more than a factor of three in the Hall mobility. These results are consistent with the hypothesis that acceptors are removed by such a quenching process. Various experiments designed to identify the mechanisms associated with these changes will be described.

[1] J. R. Dixon, Phys. Rev. **107**, 374 (1957).

**L3. Electron Effective Mass Variation in InAs and InSb.** FRANK STERN, *Naval Ordnance Laboratory*.—The electron effective mass in degenerate InAs and InSb shows substantial variation with donor concentration ($N_D$). In Table I are tabulated[1] the density-of-states mass, $m_d=\hbar^3k^2/2E$, the electric susceptibility mass,[2] $m_s=\hbar^2k/(dE/dk)$, and the effective mass at the Fermi level, $m_f=\hbar^2/(d^2E/dk^2)$; all three expressions are evaluated at $k_F=(3\pi^2N_D)^{\frac{1}{3}}$.

TABLE I.

| | Indium arsenide | | | Indium antimonide | | |
|---|---|---|---|---|---|---|
| $N_D$ | $m_d/m$ | $m_s/m$ | $m_f/m$ | $m_d/m$ | $m_s/m$ | $m_f/m$ |
| $3\times10^{16}$ | 0.024 | 0.025 | 0.028 | 0.015 | 0.016 | 0.023 |
| $10^{17}$ | 0.025 | 0.026 | 0.034 | 0.016 | 0.019 | 0.038 |
| $3\times10^{17}$ | 0.026 | 0.029 | 0.048 | 0.019 | 0.024 | 0.075 |
| $10^{18}$ | 0.029 | 0.036 | 0.086 | 0.023 | 0.032 | 0.20 |
| $3\times10^{18}$ | 0.034 | 0.045 | 0.18 | 0.029 | 0.045 | 1.0 |
| $10^{19}$ | 0.043 | 0.064 | 0.58 | 0.039 | 0.067 | −1.0 |
| $3\times10^{19}$ | 0.056 | 0.090 | 5.3 | 0.054 | 0.102 | −0.5 |

[1] These effective masses were calculated using Kane's method of finding the band structure [E. O. Kane, J. Phys. Chem. Solids **1**, 249 (1957)]. In Kane's notation, we worked in the $\langle r\rangle$ directions and used the following values of the parameters for InAs and InSb, respectively: $E_G=0.42$, 0.23; $\Delta=0.46$, 0.90 ev; $B=-2.0$, $-4.5\hbar^2/2m$; $C=-4.0$, $-7.5\hbar^2/2m$; $D=-0.6$, $-0.7\hbar^2/2m$; $P=0.63, 0.65c\hbar$; $A=F=G=0$.
[2] W. G. Spitzer and H. Y. Fan, Phys. Rev. **106**, 882 (1957), Eq. (11).

**L4. Oscillatory Magnetoresistance of InSb and InAs.** H. P. R. FREDERIKSE AND W. R. HOSLER, *National Bureau of Standards*.—The transverse and logitudinal magnetoresistance of InSb ($n=1-7\times10^{15}$/cc and InAs ($n=2\times10^{16}$/cc at helium temperatures show oscillations which are periodic in $1/H$; this behavior is due to the quantization of the electron orbits. Theory predicts the minima of the magnetoresistance to occur when $\zeta_H=(n+\frac{1}{2})\hbar\omega$ ($\zeta_H$=Fermi energy in field; $\omega$=cyclotron frequency). $\zeta_H$ is related to $\zeta_0$ (zero field value) and can be calculated from the number of carriers. The observed period of oscillation is in reasonable agreement with the above formula. The amplitude $A$ of the oscillations decreases with decreasing magnetic field strength: $A\sim\exp[-2\pi^2k(T+T')/\beta^*H]$, where $\beta^*$ is the effective double Bohr magneton and $T'$ is a virtual temperature increase which expresses the influence of collision broadening.[1] Values of $\beta^*$ and $T'$ have been deduced from the experimental data. Results for $\beta^*$ correspond to effective electron masses of 0.01 $m_0$ (for InSb) and 0.02 $m_0$ (for InAs). The values of $T'$ are in excellent agreement with the observed mobilities.

[1] R. B. Dingle, Proc. Roy. Soc. (London) **A211**, 500 (1952).

**L5. Magnetic Field Dependence of the Hall Coefficient in InSb.*** R. T. BATE, R. K. WILLARDSON, AND A. C. BEER, *Battelle Memorial Institute*.—The Hall coefficient was measured as a function of magnetic field from 20 to 20 000 gauss at fixed temperatures in the region between 50°K and 300°K. The $n$-type InSb had carrier concentrations of about $1\times10^{14}$ cm$^{-3}$ mobilities of about $5\times10^5$ cm$^2$/v-sec at 50°K. The corresponding values for the $p$-type sample were $1\times10^{15}$ cm$^{-3}$ and $1\times10^4$ cm$^2$/v-sec, respectively. In the extrinsic region, the variation of the Hall coefficient with magnetic field ranged between 5% and 20% for $n$-type samples, and between 20% and 40% for the $p$-type. In all samples a broad minimum occurred between 1000 and 10 000 gauss. In the intrinsic range, the variation in the Hall coefficient for the $n$-type specimens was about 15%. For all specimens at all temperatures used, the absolute value of the Hall coefficient was largest at low fields. Implications of the data are discussed with regard to scattering processes, quantization effects of large magnetic fields, and band structural considerations, including anisotropy and warping of the energy surfaces, and valence band degeneracy.

* This research was supported by the U. S. Air Force, through the office of Scientific Research of the Air Research and Development Command.

**L6. Carrier Trapping Effect in Indium Antimonide.*** R. A. LAFF AND H. Y. FAN, *Purdue University*.—Photoconductivity was measured on single crystals of $p$-type InSb with impurity concentration 1 to $3\times10^{14}$ cm$^{-3}$. The carrier lifetime deduced decreases with decreasing temperature down to 130°K, but rises again at still lower temperatures. The PEM effect yields the same lifetime above 130°K. Below 130°K, the lifetime deduced from PEM effect continues to decrease, reaching a constant value of $10^{-9}$ second. Drift mobility measurements indicate the trapping of minority carriers in the low-temperature region. From the delay time of the collector signal as compared to the expected transit time, a value of 72 was estimated for the ratio of trapped to free electrons at 78°K. The steady-state collector signal measured as a function of emitter-collector distance gave the hole electron recombination time to be $6\times10^{-8}$ second. About the same value is obtained from the photoconductivity when the trapping effect is taken into account. Trapping effect was not observed at 135°K. Evidence of minority carrier trapping is also found in the magnetoresistance of optically excited carriers when light is uniformly absorbed in the sample. The magnetoresistance is much smaller than that of $n$-type samples of comparable impurity concentration.

* Work supported by an Office of Naval Research Contract.

**L7. Some Properties of HgTe and HgSe.** R. O. CARLSON, *General Electric Research Laboratory*.—Polycrystalline HgTe and HgSe with the zincblende structure have been prepared in sealed quartz tubes. As prepared, HgTe had acceptor concentrations of $10^{18}$–$10^{19}$ cm$^{-3}$, hole mobilities of ~100 cm$^2$/volt-sec, and electron mobilities up to 8000 cm$^2$/volt-sec. Even at this impurity level, both Hall coefficient and thermoelectric power are negative at room temperature because of the small band gap (~0.1 ev) and the high mobility ratio. The Hall coefficient changes sign at temperatures as low as 20°K. The dependence of Hall coefficient on magnetic field is reminiscent of data on $p$-type germanium[1] and suggests that there are two or more negative charge carriers with different effective masses. Zinc acts as a donor, copper as an acceptor in HgTe. The HgSe samples were $n$-type with $5\times10^{18}$ electrons/cm$^3$, similar to samples of Blum and Regel.[2] These samples show a negligible magneto-Hall effect.

[1] Willardson, Harman, and Beer, Phys. Rev. **96**, 1512 (1954).
[2] A. I. Blum and A. R. Regel, J. Tech. Phys. (U.S.S.R.) **21**, 316 (1951).

**L8. Electronic Specific Heat of Degenerate $n$-Type Silicon.*** G. SEIDEL AND P. H. KEESOM, *Purdue University*.—The

specific heat of two 90 g $n$-type single crystals of silicon has been measured in the temperature range from 1.2°K to 4.2°K. Since these samples were degenerate, the specific heat was composed of a lattice contribution and an electron contribution and can be represented by an equation of the form $C=\alpha T+\gamma T^3$. The carrier concentration of the samples was determined from Hall coefficient measurements. It is then possible to compute the density of states effective mass for which both samples give essentially the same value. For comparison with cyclotron resonance measurements we calculate with the number of conduction band minima $\nu=6$, $(m_1m_t^2)^{\frac{1}{3}}=0.42m_0$; or with $\nu=3$, $(m_1m_t^2)^{\frac{1}{3}}=0.66m_0$. Since cyclotron resonance gives the value of $0.33m_0$, it would appear that $\nu=6$ is to be preferred.

* This work was supported by a Signal Corps contract.
† These samples were kindly supplied by the Texas Instrument Company.

**L9 Surface Photo- and Magnetoconductive Effects in Ge.*** R. CUNNINGHAM AND R. BRAY, *Purdue University.*—Surface studies were carried out on $p$-type, Au-doped Ge at ~85°K. Bulk resistivity of $\sim 10^6$ ohm-cm permits surface induced conductance changes of several orders of magnitude to be observed. Such changes, produced by illumination, have a nonexponential rise and decay and may take days to reach steady state. Complete recovery required heating. These slow effects could be produced only with *ultraviolet* irradiation ($h\nu \geq 3$. ev), and on oxidized surfaces, but not on surfaces reduced in HF etch. An explanation of these results is that electrons are excited over a 3-ev oxide barrier, and trapped in the slow surface states, leaving behind excess holes to form a conducting accumulation layer. External field-effect measurements show that the surface is initially near the conductance minimum, but becomes strongly $p$-type after irradiation. Hall[1] and magnetoresistance measurements made after irradiation show apparently greatly reduced hole mobility, qualitatively confirming Schrieffer's prediction[2] of reduced mobility for carriers restricted to a narrow space charge layer at the surface.

* Work supported by Signal Corps Contract.
† The Hall measurement was kindly made by D. Kleitman.
‡ J. R. Schrieffer, Phys. Rev. 97, 641 (1955).

**L10. Two-Band Exciton Model in Insulators.** BERNARD GOODMAN AND ORDEAN S. OEN, *University of Missouri.*—The model of an exciton as a conduction-band electron bound to a hole in the valence band is discussed using the creation and annihilation operators of second quantization. These operators are defined for the approximate Hartree-Fock states where the potential operator is always that for the ground-state occupation numbers. The effective Hamiltonian for the exciton contains in addition to the direct two-particle interaction a term arising from the exchange of the excited electron with the valence-band electrons which cannot be described as an exchange with the hole. A similar term (the "annihilation" term) in the theory of positronium can be converted into a spin-dependent electron-hole operator using properties of low energy Dirac functions. This simplification does not apply here because of the more complicated wave functions but an estimate of the exchange term can be made when the exciton is diffuse compared with the interatomic distance.

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## SATURDAY MORNING AT 9:30

## Wilson Auditorium

(R. D. SARD presiding)

### *Scattering and Polarization; Mesons; Cosmic Rays*

**M1. Determination of Electron Polarization by Electron-Electron Scattering: $Y^{90}$ and $Au^{198}$.*** N. BENCZER KOLLER, A. SCHWARZSCHILD, J. B. VISE, AND C. S. WU, *Columbia University.*—The polarization of the $\beta$ particles from $Y^{90}$ and $Au^{198}$ has been investigated by using electron-electron scattering. The magnetic foil used was a thin Supermendur sheet. A lens consisting of two permanent quadrupole magnets was used to improve the relative intensity of electrons of high energy to those of low energy. The reliability of this method and the precautions necessary in its application will be illustrated and discussed. It was found that for both $Y^{90}$ and $Au^{198}$ the polarization is $[-(v/c)]$. The theoretical implications to the coupling constants of $\beta$ interactions will be presented.

* This work was partially supported by the U. S. Atomic Energy Commission.

**M2. Longitudinal Polarization of Beta Particles from $P^{32}$.*†** C. R. DULGEROFF, E. D. LAMBE, AND T. A. POND, *Washington University.*—A horizontal beam of $P^{32}$ electrons is incident on an aluminum foil (typically 0.008 in.) alternately from the east and the west. Electrons multiply scattered downward through 90° are analyzed for transverse polarization by comparison of Mott scattering rates through angles of 75° from vertical in north and south azimuth. For gold thickness below 0.5 mg/cm² (thinnest used: 0.18 mg/cm²) a constant asymmetry is observed: ratio of north to south scattering rates with source in east, divided by the same ratio with source in the west is $0.840\pm0.015$. The asymmetry decreases with thicker gold scatterers, indicating the onset of plural scattering. An initial longitudinal polarization of $v/c$ integrated over the measured spectrum analyzed in the Mott scattering leads to a value of the above ratio $0.746\pm0.050$, the uncertainties lying in the absorption and energy loss corrections to the spectrum. This value includes a correction for the precession of the spins coupled to the multiple scattering process,[1] but does not allow for any further depolarizations.

* Supported in part by the Office of Naval Research and Office of Scientific Research.
† A preliminary report made at the American Physical Society meeting, Washington, D. C., April 27, 1957, is extended in this paper.
‡ We are indebted to Professor G. W. Ford for valuable remarks on this effect.

**M3. Electron-Electron Scattering at 1.0, 1.5, and 2.0 Mev.*** J. J. KEPES, B. WALDMAN, AND R. L. WALTER, *University of Notre Dame.*—Monoergic electrons from an electrostatic generator were scattered by 0.5-, 1.0-, and 1.5-mil nylon foils at a laboratory angle of 30°. The scattered electrons were magnetically analyzed and detected by a scintillation counter. The differential cross section for electron-electron scattering was evaluated by comparison with the electron-nuclear scattering. The experimental cross sections at 1.5 and 2.0 Mev agree with Møller's theory within 5%, but that at 1.0 Mev is 20% low. The width at half-maximum of the scattered electron energy distribution is about 10% for the thinnest foil.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**M4. Scattering of 1.6-Mev Electrons by Thick Foils.*** W. C. MILLER, J. J. KEPES, AND M. F. SHEA, *University of Notre Dame.*—The momentum distribution of electrons scattered at 90° by foils in the reflection position has been measured. The foils used were aluminum, copper, silver, and and gold of thickness ranging from 20 mg/cm² upward. The distributions were unaltered by an increase of foil thickness above 200 mg/cm² for all $Z$'s. For the thickest foils used the low energy portions were independent of $Z$; however the higher $Z$'s scattered many more high-energy electrons.

* Supported in part by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.

**M5. Polarization Measurements in $p$-$\alpha$ Elastic Scattering.*** MARY JEAN SCOTT, *Brookhaven National Laboratory.*—The polarization of protons elastically scattered from alpha particles was observed by measuring the asymmetry obtained by doubly scattering protons in helium. Protons from the BNL Van de Graaff generator entered a helium-filled double scattering chamber through a 50-microinch nickel window. The first scattering was at either 104° 29′ (c.m.) or 73° 38′ (c.m.) and the second scattering was to left and right at 73° 38′ (c.m.). The doubly scattered protons were detected by 50 $\mu$ Ilford C-2 plates. The polarization product, $P_aP_b$, was calculated from the left-right ratio ($R$) using the formula $R=(1+P_aP_b)/(1-P_aP_b)$, where $P_a$ and $P_b$ are the polarizations at the first and second scattering, respectively. Three interdependent measurements, in which $P_aP_b$ was equal to $P_1P_2$, $P_1P_3$, or $P_2P_3$, yielded values for $P_1$[3.58 Mev, 104° 29′ (c.m.)], $P_2$[2.02 Mev, 73° 38′ (c.m.)], and $P_3$[1.375 Mev, 73° 38′ (c.m.)]. Preliminary results given below agree with those calculated from the single scattering phase shifts given by Critchfield and Dodder.[1]

| Experimental | Calculated |
|---|---|
| $P_1$ 0.55 ± 0.04 | 0.59 ± 0.13 |
| $P_2$ 0.80 ± 0.04 | 0.80 ± 0.04 |
| $P_3$ 0.64 ± 0.04 | 0.59 ± 0.16 |

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. L. Critchfield and D. C. Dodder, Phys. Rev. **76**, 602 (1949).

**M6. Elastic Scattering of Protons from $A^{40}$.*** G. D. FREIER, K. F. FAMULARO,† D. M. ZIPOY,‡ AND J. LEIGH, *University of Minnesota.*—The elastic scattering of protons from $A^{40}$ has been measured for incident proton energies of 1.75 Mev to 2.75 Mev and at a laboratory angle of 155°. The differential cross sections are close to Rutherford values except for strong resonances at approximately 1.90 Mev and 2.48 Mev. At these two energies, angular distributions were measured between angles of 70° and 160°. The scattering was found to be Rutherford at the smallest angle and deviate from this as one approached the larger angles.

* This work supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
† Now at Los Alamos Scientific Laboratory.
‡ Now at Cornell University.

**M7. Elastic Scattering of 21.6-Mev Deuterons.*** J. L. YNTEMA, *Argonne National Laboratory.*—The elastic scattering of 21.6-Mev deuterons has been measured for several elements using the Argonne 60-inch scattering chamber. The collimated beam has a diameter of 3 mm at the target. The scattered particles were detected with sodium iodide crystals 0.0400 ± 0.0005 in. thick. A remotely controlled foil changer permits the insertion of aluminum absorbers from 0- to 0.150-in. thick in steps of 0.001 in. and is adjusted to give maximum pulse height. The angle of the detector is determined to better than 0.05° and can be remotely set at any angle between 5° and 174°. The solid angle intercepted by the detector is known to better than 0.1%. Angular distributions of elastic scattering by Cu, Ni, and Zn from about 10° to 105° will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**M8. Photoproduction of $\pi^0$ Mesons in Hydrogen.*** L. J. KOESTER, E. L. GOLDWASSER, P. B. MILLER, AND G. E. MODESITT.†—A scintillation counter telescope was used to count $\gamma$ rays from the decay of $\pi^0$ mesons produced in a liquid hydrogen target. Data were taken at laboratory angles of 40°, 65°, 90°, and 145°, at betatron energies between 145 Mev and 295 Mev in 10-Mev intervals. The photon difference method was used to determine the angular distribution coefficients $A$, $B$, and $C$ as functions of the incident photon energy. The results are compared with the Chew-Low theory.

* This work supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
† National Science Foundation Predoctoral Fellow.

**M9. Angular Distributions in $\pi$-$\mu$ Decay.*** P. L. CONNOLLY AND G. R. LYNCH, *Cornell University.*—Two stacks of Ilford G-5 emulsions have been exposed to $\pi^+$ mesons produced in a hydrogen target at the Cornell synchrotron. The stopping pions were produced by 300-Mev photons at 90° in the center-of-mass system. No magnetic analysis was used. Scanning for stopping pions was done by track following. Angular distributions of the decay meson have been measured. We define $\mathbf{z}$ as $\mathbf{p}\times\mathbf{k}$ and $\mathbf{L}$ as $\mathbf{z}\times\mathbf{p}$, where $\mathbf{p}$ and $\mathbf{k}$ are the pion and photon momentum, respectively. At the time of writing the following results have been obtained.

$$\frac{B-F}{B+F}=0.037\pm0.030 \qquad \frac{L-R}{L+R}=0.000\pm0.030$$

$$\frac{D-U}{D+U}=0.022\pm0.030.$$

Here $B$ signifies the number of events in which the initial direction of the muon is in the hemisphere of negative $p$ components and similarly for the other symbols. Detailed angular distribution will be reported.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**M10. Cosmic-Ray Decrease of 29 August, 1957, and Associated Soft Radiation.** KINSEY A. ANDERSON, *University of Iowa.*—During a balloon flight made from Fort Churchill, Manitoba on 29 August, 1957 a decrease in the cosmic-ray intensity was encountered beginning at about 2050 U.T. This decrease was accompanied by a radiation which appeared in the single counter and Neher-type ionization chamber but not in the vertical counter telescope. This radiation first appeared at 1915 U.T. and persisted but with large and rapid fluctuations until the balloon began sinking rapidly after sunset six hours later. This extra radiation is probably the soft radiation first identified by Meredith[1] *et al.* in rocket flights and lately by Winckler[2] at balloon altitudes. No appreciable part of the effect could be due to protons or heavier nuclei since in that case the telescope should have increased its rate. The data appear to be consistent with a mixture of x-rays and electrons of energy less than 600 kev. During undisturbed periods the cosmic-ray intensity is considerably below that reported for that latitude in past years

[1] Meredith, Gottlieb, and Van Allen, Phys. Rev. **97**, 201 (1955).
[2] J. R. Winckler (to be published).

**M11. Helium Distribution in the Meteorite Carbo.*** JOHN H. HOFFMAN AND A. O. NIER, *University of Minnesota.*—It has been established that meteorites contain $He^3$ and $He^4$ produced by high-energy cosmic-ray particles interacting with the nuclei of the meteorite material. Paneth *et al.*,[1] have

measured the helium content and isotopic ratio of shavings from two holes drilled in the iron meteorite, Carbo, and have found a definite depth dependance for both quantities. Recently this meteorite has been cut in half and a slice removed from one of the halves.† The $He^3$ and $He^4$ distribution throughout this slice has been studied. Approximately 250 mg samples were melted in an induction furnace and the gas thus released was purified with activated charcoal. The helium was measured on a double-focusing mass spectrometer using the recirculating technique and calibrated with known quantities of standard mixtures of $He^3$ and $He^4$. The results of these measurements will be discussed.

* Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Paneth, Reasbeck, and Mayne, Nature 172, 200 (1953).
† Samples obtained through the cooperation of Dr. E. L. Fireman, Harvard Astrophysical Observatory.

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## SATURDAY MORNING AT 9:30

## Brown 118

(F. B. SHULL presiding)

### *Reactions of Transmutation and Nuclear Energy Levels*

**N1. Total Proton Reaction Cross Sections at 34 Mev.*** J. T. GOODING, *University of Minnesota.*—The total reaction cross sections of C, Al, Fe, Sn, and Pb for protons of energy 34±2.5 Mev have been measured in an attenuation type experiment. The 40-Mev beam of the Minnesota linear accelerator is passed through a counter telescope consisting of three thin $dE/dx$ counters in fast coincidence, and a stopping "$E$" counter in anticoincidence with the $dE/dx$ counters. The targets, approximately 5 Mev thick, are inserted between the $dE/dx$ and $E$ counters, and the reaction cross sections are calculated from the anticoincidence differences between target in and target out runs. In the target out measurements a dummy absorber is placed in front of the $dE/dx$ telescope to keep the energy at the $E$ counter, and thus the nuclear reactions in the $E$ counter, the same as for the target in measurements. The experimental results are in good agreement with the predictions of optical model calculations using parameters obtained from fitting the elastic scattering data.[1] For the light elements the reaction cross-section measurements are able to distinguish between the sets of optical model parameters giving equally good fits to the elastic scattering data.[2]

* This work is supported in part by the U. S. Atomic Energy Commission.
[1] N. Hintz, University of Minnesota Linear Accelerator Laboratory Annual Progress Report 1956–1957 (March, 1957).
[2] A. E. Glassgold, University of California, Berkeley (private communication).

**N2. Angular Distribution of $D(d,n)He^3$ Neutrons.*** J. M. FOWLER AND W. DAEHNICK, *Washington University.*—The angular distribution of neutrons from the reaction $D(d,n)$ $He^3$ has been obtained over the angular range of 0–90° center-of-mass at a deuteron energy of 9.0 Mev. The neutrons were detected with a 1 in. ×1 in. ×5 mm plastic scintillator and the photomultiplier pulses were displayed on a multichannel, Hutchinson-Scarrott, pulse-height analyzer. The target was deuterium gas at 200 lb per sq in. and the background was measured by comparing "gas in" and "gas out" bombardments. The experimental angular distributions are being compared with the Legendre coefficients found by Brolley *et al.*,[1] and with the predictions of the "exchange stripping" theory.

* Supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.
[1] Brolley, Putman, and Rosen, Phys. Rev. 107, 820 (1957).

**N3. Positions and Widths of Two Levels in $Li^7$.*** CORNELIUS P. BROWNE, *University of Notre Dame.*—Nuclear track plates exposed in the MIT broad-range spectrograph have been scanned for proton groups emitted from LiOH targets under deuteron bombardment. The high resolution of the spectrograph allowed a direct measurement of the widths of two levels in $Li^7$. Bombarding energies were 7.0 and 7.5 Mev and angles of observation were 30, 70, and 90 degrees. At excitation energies below 7.5 Mev the three previously known levels at 0.47, 4.6, and 7.5 Mev were seen. This experiment gave an excitation of 4.630 Mev, with a natural width of 93±8 kev for the second level and an excitation of 7.457 Mev with a width of 91±8 kev for the third level. No level was found at 5.5 Mev. The level seen by other investigators at 6.6 Mev was not seen, perhaps because of a very large width and/or a low cross section.

* Supported by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.

**N4. Angular Distributions of the $Be^9(d,p)Be^{10}$ and $Be^9(d,t)Be^8$ at Low Deuteron Energies.** G. L. HARMON* AND C. D. CURTIS, *Vanderbilt University.*—By use of scintillation counters, measurements similar to those reported earlier[1] have been made for effective deuteron energies of approximately 285, 225, and 150 kev. Where energies are comparable, the angular proton distributions are in agreement with those of other published work.[2,3] The triton distuributions are in general agreement showing some peaking in the backward hemisphere.

* Present address: Glenn L. Martin Company.
[1] Hyder, Harmon, and Curtis, Bull. Am. Phys. Soc. Ser. II, 2, 267 (1957).
[2] DeJong, Endt, and Simons, Physica 18, 676 (1952).
[3] R. K. Smither, Phys. Rev. 107, 196 (1957).

**N5. Angular Distributions of the $B^{10}(d,p)B^{11}$ Reaction at Low Deuteron Energies.** GORDON RAY HARRISON* AND CYRIL D. CURTIS, *Vanderbilt University.*—Angular distribution measurements have been made for the first three proton groups from the $B^{10}(d,p)B^{11}$ reaction at deuteron energies of $E_d$=0.295, 0.260, 0.215 Mev. An angular distribution of the ground-state group was also measured at $E_d$=0.175 Mev. Differential and total cross sections were obtained at all the deuteron energies. The angular distributions were measured from 0° to 140° (lab system) by means of a scintillation spectrometer. A 1 mm thick CsI (Tl) crystal mounted on an RCA 5819 photomultiplier tube was used in the detector head of the spectrometer. The CsI crystal response for protons was found to be linear within experimental error up to 8.6 Mev. A 300-kev Cockcroft-Walton accelerator was used to produce the deuterons. The targets were prepared by vacuum evaporation of enriched $B^{10}$ from small carbon boats by resistive heating. Targets of thicknesses from 50 to 70 $\mu g/cm^2$ could be prepared quite readily. Relative proton yields were measured to better than 2% accuracy while absolute differ-

ential and total cross sections were measured with accuracies of the order of 10% due chiefly to insufficient knowledge of target thickness. Very good agreement was obtained with some earlier work done in this energy region by other investigators.[1]

* Present address: Sperry Gyroscope Company.
[1] Paris, Valckx, and Endt, Physica **20**, 573 (1954).

**N6. Reactions $B^{11}(\gamma,2p)$ and $C^{13}(\gamma,3p)$.*** G. W. TAUTFEST, *Purdue University*.—The Purdue University synchrotron has been used to study the yields of $Li^9$, a delayed neutron emitter, from carbon and boron targets. The $Li^9$ is identified by its characteristic lifetime for neutron emission. The neutrons are detected in an array of enriched $BF_3$ counters surrounded by a carbon moderator; the absolute detection efficiency is 1.8%. The excitation functions have been studied from 130–320 Mev and are consistent with the assumption that most of the yield is due to resonances below 100 Mev. The integrated cross sections under this assumption are $(4.2\pm0.2)\times10^{-4}$ Mev-barns for boron and $(5.3\pm0.3)\times10^{-4}$ Mev-barns for carbon.

* Supported in part by U. S. Atomic Energy Commission.

**N7. Studies of the First Excited State Transition in the Reaction $B^{11}(d,n)C^{12*}(\gamma)C^{12}$.** OLAF RASK, OAKES AMES, S. EDWARDS, JR., L. MADANSKY, AND G. E. OWEN, *The Johns Hopkins University*.—The angular distributions of the neutrons to the first excited state in the reaction $B^{11}(d,n)C^{12*}$ have been obtained. Direct interaction theory combining deuteron stripping and heavy particle theory is sufficient to account for the angular distributions. The $n,\gamma$ correlations for direct interactions of this type can be different for different settings of the neutron counter. The axes of quantization for gamma rays from the first excited state when formed by the heavy particle channel are in general different than the axis of quantization produced in the deuteron stripping channel. Hence the variations in the population of the substates can produce different correlations for the two channels. Theoretical analysis indicates an essentially isotropic correlation for the heavy particle channel and a $1+\cos^2\phi$ correlation for the deuteron stripping channel. Results of preliminary correlation experiments at neutron angles of 45° and 135° will be presented.

**N8. Angular Distributions of Neutrons from the $(d,n)$ Reaction on $B^{11}$.*** B. ZEIDMAN AND J. M. FOWLER, *Washington University*.—The complete angular distributions, from 10° to 160°, of neutrons from the $(d,n)$ reactions on $B^{11}$ leading to the ground and first excited state of $C^{12}$ have been obtained at an incident deuteron energy of 10 Mev. The neutrons were detected by a recoil proton telescope consisting of a hydrogenous radiator and two proportional counters operated in coincidence with a scintillation counter. The angular distributions at forward angles have peaks as predicted by the Butler stripping theory with $l_p=1$. At large angles the distributions for both groups exhibit a nonisotropic structure. Analysis of the distributions in terms of the Owen-Madansky[1] "exchange" stripping theory will be discussed. A preliminary analysis indicates that a value of $l_d=0$, for the angular momentum with which the deuteron is captured and equal probabilities for the forward and backward stripping components gives an adequate fit for the ground-state data.

* Supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.
[1] G. E. Owen and L. Madansky, Phys. Rev. **106**, 1766 (1957).

**N9. Gamma-Ray Excitation of the 15.1-Mev Level in $C^{12}$.*** E. L. GARWIN AND A. S. PENFOLD, *University of Chicago*.—The 15.1-Mev, $T=1$, level in $C^{12}$ was excited with carbon-filtered 40-Mev bremsstrahlung and the resulting radiations were detected in NaI. The ground-state yield was measured for many thicknesses of carbon filter. Comparison to theoretical curves for doppler broadened resonance cross sections[1] gave the following level parameters: 130±3 ev total width; 100±3 ev radiative width (ground state); 3.5±1 ev radiative width (first excited state); 24.8±0.5 barns peak cross section; 4.0±0.2 mb-Mev integrated scattering cross section. A 5% background, not strongly affected by the filters, and associated with levels between 13 and 16 Mev was observed (0.45 g/cm² carbon target). All the above results are in serious disagreement with a previous experiment.[2] Using the foregoing results, the observable ground state yield for target thicknesses to 12 g/cm² was predicted. Excellent agreement with experiment was obtained. Fifteen points on the angular distribution for the ground state transition, between 45 and 135 degrees, were obtained (8% error each). The transition is dipole.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Handbuch der Physik **XL**, 380 (1957).
[2] E. Hayward and E. Fuller, Phys. Rev. **106**, 991 (1957).

**N10. Gamma Rays from Excited States of $Ne^{20}$.*** T. H. KRUSE, R. D. BENT, AND L. J. LIDOFSKY, *Columbia University*.—Gamma rays from excited states of $Ne^{20}$ have been observed with scintillation spectrometers using the Columbia Van de Graaff accelerator. The 4.2- and 4.9-Mev states of $Ne^{21}$ decay strongly through the 1.6-Mev state. The ground state branch for both of these states is less than 10% that to the first excited state. Gamma rays of 2.6 and 3.3 Mev have been observed in coincidence with 1.6-Mev gamma rays from the $Na^{23}(p,\alpha)$ reaction at bombarding energies of 5 Mev and higher. A 2.6-Mev gamma ray has been observed in coincidence with the inelastic proton group to the 4.2-Mev state from the $Ne^{20}(p,p')$ reaction (natural neon) at 5.85-Mev bombarding energy. Gamma rays of 2.6 and 3.3 Mev have been observed with a three-crystal pair spectrometer from a $Na^{23}+p$ bombardment. A three-crystal pair spectrometer was also used to observe high-energy gamma rays from the $F^{19}(d,n)$ reaction. Gamma rays assigned to $Ne^{20}$ were observed with energies of 10.6, 10.1, 9.4, 8.4, and 7.2 Mev. Other gamma rays which have not been assigned were observed at 6.1, 5.2, 3.7, 3.0, and 2.5 Mev.

* This work was partially supported by the U. S. Atomic Energy Commission.

**N11. Angular Distributions of Two Proton Groups from the Reaction $Na^{23}(d,p)Na^{24}$.*** CHARLES E. DICKERMAN,† *State University of Iowa*.—The resolved angular distributions of $Na^{23}(d,p)Na^{24}$ protons leaving $Na^{24}$ in the 0.472- and 0.564-Mev levels have been obtained with a double-focusing magnetic spectrometer, using a bombarding energy of 2.95 Mev (lab.). The angular distribution corresponding to the transition to the 0.472-Mev level shows evidence of a large contribution from compound nucleus formation. A Butler-type analysis of the angular distribution of protons leading to the 0.564-Mev level indicates that this level must have spin $1^+$ or $2^+$.

* This work was supported in part by the U. S. Atomic Energy Commission.
† Now at Argonne National Laboratory.

**N12. $\gamma,2p$ Reaction in Aluminum.** J. P. DAVIDSON,* A. P. PATRO,† R. WOLDSETH,‡ *Joint Establishment for Nuclear Energy Research, Norway*.—Disks of aluminum were irradiated for five minutes just outside the doughnut of the Oslo Radium Hospital's Brown Boveri betatron. Several irradiations of each energy at one-Mev intervals between the $(\gamma,2p)$ threshold and 31 Mev were made. The resulting radioactivity was detected by a thin window Geiger counter and recorded by a pen recorder. The decay was observed for six $Na^{24}$ half-lives.

In order to verify the formation of $Na^{25}$ its characteristic gamma radiation was observed with a one-inch NaI(Tl) crystal. This survey revealed gamma lines of the correct energy with the one-minute $Na^{25}$ half-life. The beta-decay data were analyzed and the yield of the $Al^{27}(\gamma,2p)Na^{25}$ reaction relative to the combined (and unresolved) $Al^{27}(\gamma,n)Al^{26}$ and the $Al^{27}(\gamma,2n)Al^{25}$ reactions obtained. These yields are consistent with those of M. L. Perlman and G. Friedlander[1] at higher energies. A general description of the experiment and its results will be given.

* Present address: Rensselaer Polytechnic Institute.
† Present address: C.E.R.N., Geneva, Switzerland.
‡ Present address: Washington University.
[1] M. L. Perlman and G. Friedlander, Phys. Rev. **74**, 442 (1948).

**N13. Mass Distribution in Fission.*** L. W. ROELAND,† L. M. BOLLINGER, AND G. E. THOMAS, *Argonne National Laboratory.*—Application of the collective model to fission[1,2] leads to the expectation that the mass distribution of fission fragments depends on the spin state of the resonance responsible for the fission. To test this prediction, the mass distribution has been measured for resonances in $U^{233}$ and $U^{235}$. A double ionization chamber with Frisch grids was used. Pulses $V_1$ and $V_2$ produced by the two fission fragments were amplified. The ratio of $V_1$ to $(V_1+V_2)$, which is approximately proportional to the mass of one fragment, was then converted into a time difference and recorded in a 1024-channel time analyzer, giving a measure of the distribution in mass. Filters were used to select the incident neutron energy. In $U^{233}$, the mass distribution for the resonance at 1.8 ev was compared with the distribution for thermal neutrons. The fission cross sections at these two energies are thought to be associated with different spin states. The mass distributions obtained are the same within the experimental accuracy. Work is now in progress on $U^{235}$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Guest physicist from the University of Amsterdam.
[1] A. Bohr, *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva 1955* (United Nations, New York, 1956), Vol. II, p. 151.
[2] J. A. Wheeler, *Proceedings of the Conference on Neutron Physics by Time-of-Flight, Gatlinburg 1956*, ORNL-2309, p. 157.

**N14. Distribution of Nuclear Charge in the Proton-Induced Fission of $Th^{232}$.*** B. D. PATE, *Brookhaven National Laboratory and McGill University,* AND J. S. FOSTER AND L. YAFFE, *McGill University.*—Independent formation cross sections for $I^{130}$, $I^{131}$, $Te^{131}$, $I^{132}$, and $I^{134}$ and cumulative formation cross sections for $Te^{132}$, $I^{133}$, and $I^{135}$ in the $Th^{232}(p,f)$ reaction have been measured radiochemically using $4\pi$ counting.[1] Bombardments with protons in the energy range 8–87 Mev were performed with the McGill synchrocyclotron. These data have been combined with published information on mass distributions[2] to give charge distribution curves in the mass region 130–135 at five bombarding energies. Consistent with previously published data,[3,4] these display with increasing energy a shift of most probable charge toward stability and concomitant widening of the distribution. The experimental results are compared with those from calculations based on models of nuclear cascade and evaporation processes.

* Research in part supported by the Defence Research Board of Canada and in part performed under the auspices of the U. S. Atomic Energy Commission.
[1] B. D. Pate and L. Yaffe, Can. J. Chem. **33**, 610 (1955); **33**, 929 (1955); **34**, 265 (1956).
[2] H. A. Tewes and R. A. James, Phys. Rev. **88**, 860 (1952).
[3] A. C. Wahl, Phys. Rev. **99**, 730 (1955).
[4] Aagaard, Andersson, Burgman, and Pappas, J. Inorg. Nuclear Chem. (to be published).

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SATURDAY MORNING AT 9:30

Louderman Auditorium

(E. U. CONDON presiding)

## *Symposium on Design and Utilization of High-Energy Accelerators*

**P1. Mura Developments of FFAG Accelerators.** D. W. KERST, *Midwestern Universities Research Association (now with General Atomic).* (30 min.)

**P2. Studies of the Model Magnet for the Argonne Proton Synchrotron.** MARTYN FOSS, *Argonne National Laboratory.* (30 min.)

**P3. Proposed External Beams for the Argonne Accelerator.** S. C. WRIGHT, *University of Chicago.* (30 min.)

**P4. Experimental Facilities on the University of Chicago Synchrocyclotron.** A. V. CREWE, *University of Chicago.* (30 min.)

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SATURDAY MORNING AT 9:30

Wayman Crow, 101

(A. V. BUSHKOVITCH presiding)

## *Theoretical Physics, I*

**Q1. Lorentz-Covariant Quantization in Presence of Gradient Interactions.*** F. J. BELINFANTE, *Purdue University.*—Even by linearizing the Lagrangian in $\nabla$ introducing derived variables, gradient interactions are not always avoidable. All valid proofs of covariance of canonical quantization found in the literature make assumptions violated in such cases. We cover some such cases generalizing an old proof[1] by allowing that (1) $\partial L/\partial\nabla_\lambda q_\epsilon = p^\tau a_{\epsilon\tau}{}^{\lambda\kappa} + P^\tau b_\tau{}^{\lambda\kappa}$ with $q_\epsilon$-

dependent $q_\sigma, \dot{q}_\sigma$, where the "derived momenta" $P^\tau$ are Lagrangian variables ($\mathfrak{q}$), the canonical momenta $p^\sigma$ are functions of $\mathfrak{q}$, and the canonical variables $(q_\sigma, p^\tau)$ and derived variables $(Q_\sigma, P^\tau)$ together determine the $\mathfrak{q}$, and (2) the coefficients $m^{i,j}$ of the terms bilinear or quadratic in derived variables[1] may be $q_\sigma$-dependent provided they commute with the derived variables and form a nonsingular matrix. The linear theory of gravitation[2] can be formulated to satisfy these conditions. Cannonical quantization then is possible, but without canonization[3] of the Lagrangian (which will destroy manifest Lorentz covariance) one cannot derive an interaction representation with integrable Schrödinger equation.

* Supported in part by the National Science Foundation.
[1] F. J. Belinfante, Physica **7**, 765 (1940).
[2] F. J. Belinfante and J. C. Swihart, Ann. Phys. **2**, 81 (1957).
[3] Belinfante, Caplan, and Kennedy, Revs. Modern Phys. **29**, 518 (1957).

**Q2. Quantization of Damped Motion.** EDWARD H. KERNER, *University of Buffalo.*—When the force of radiation damping can be represented as a frictional-type force, the Newtonian motion $m\ddot{r}+\gamma\dot{r}=-\nabla V$ may be cast into Hamiltonian form via

$$H(p,r,t)=l^{-\lambda t}p^2/2m+l^{\lambda t}V(r)\,(\lambda=\gamma/m)$$

($\gamma$ arbitrary). The Schrödinger equation $i\hbar\dot{\psi}=H(-i\hbar\nabla,r,t)\psi$ then governs the quantum motion with $\psi(r,t)$ preserving its meaning of position probability amplitude at time $t$. By suitable contact transformation, a time-free Hamiltonian (constant of the motion) may in cases be constructed; then there exists a species of stationary states in spite of energy nonconservation. The example of the damped oscillator will be discussed in detail to the end of showing how, in close correspondence to the simple classical result, the natural breadth and the shift of a spectral line occur, no perturbation calculus being needed. Though the damped motion winds down (or up, if $t$ decreases) quantally as classically, the uncertainty relations are always maintained. Some interesting statistical-mechanical implications will be mentioned.

**Q3. Outgoing Boundary Condition in Rearrangement Collisions.*** E. GERJUOY, *University of Pittsburgh.*—The boundary condition on the solution to the nonrelativistic time independent Schroedinger equation for arbitrarily complicated rearrangements of spinless particles has been carefully examined. For real energies $E$ it can be shown that the outgoing boundary condition on the scattered wave $\varphi$ need not imply that $\varphi$ is "everywhere outgoing." This and similar considerations make apparent the fact remarked by Foldy and Tobocman,[1] namely that the Lippmann-Schwinger integral equation need not have a unique solution for real energies. The relationship of this result to the added fact that solutions to the Lippmann-Schwinger integral equation are unique for complex energies $E+i\epsilon,\epsilon>0$ will be discussed, and also the relationship of the usual operator manipulations to the outgoing boundary condition.

* This work supported in part by the Office of Naval Research.
[1] L. L. Foldy and W. Tobocman, Phys. Rev. **105**, 1099 (1957).

**Q4. Time-Reversibility Properties of Mechanics Equations.** RICHARD SCHLEGEL, *Michigan State University.*—Suppose a system to pass from an initial state $S_i$ to a final state $S_f$ in time $t$. (i): The system may be said to be reversible if the reversed state $S_{f'}$ passes to the reversed state $S_{i'}$ in time $t$.[1] Two other possible definitions of reversibility are, (ii) that the system passes from $S_f$ to $S_i$ as time goes from 0 to $-t$, and (iii) that it passes from $S_{f'}$ to $S_{i'}$ as time goes from 0 to $-t$. The equation $\ddot{x}=a$, on two quadratures, gives solutions relating $t$ and $x$ which satisfy (i), if $a=f(x)$ (reversed state now means reversal of velocity). If $a=f(t)$, the integrated solutions do not satisfy (i), even though $f(t)$ is even.[2] Solutions of $\ddot{x}=a$, with $a=f(x)$ or $a=f(t)$, satisfy (ii), but the definition is contradictory in that the velocities obtained for the passage from $S_f$ to $S_i$ are in a direction that would carry the system from $S_i$ to $S_f$. Definition (iii) is satisfied by solutions of $\ddot{x}=a$ with $a=f(x)$, but not with $a=f(t)$.

[1] Adapted from S. Watanabe, Revs. Modern Phys. **27**, 31 (1955).
[2] R. Schlegel, Nature **178**, 381 (1956).

**Q5. Two-Component Wave Equation for Particles with Spin 1/2 and Arbitrary Mass Distribution.*** WILLIAM C. DAVIDON, *Argonne National Laboratory.*—By treating the proper time and the bare mass of a particle as cannonically conjugate variables, a covariant wave equation for a two-component spinor, $\psi(x,s)$, has been obtained. The state at a time can be represented by $\psi(x,s)$ and its time development determined by a linear, Hermitian Hamiltonian, which, for a free particle, is $H\psi=i(\partial\psi/\partial t)=-i[\partial\psi(s)/\partial s]-i\boldsymbol{\sigma}\cdot\boldsymbol{\nabla}\psi(-s)$ where $\sigma_\nu$ are the Pauli $2\times2$ matrices. Under a transformation to a coordinate system moving with velocity $c\tanh\alpha$ in the $z$ direction, we have $\psi'(s)=\cosh(\alpha/2)\psi(s)+\sigma_4\sinh(\alpha/2)\psi(-s)$. A scalar and vector density can be formed, $\rho=\psi^*(s)\psi(s)-\psi^*(-s)\psi(-s)$, $S_0=\psi^*(s)\psi(s)+\psi^*(-s)\psi(-s)$, $\mathbf{S}=\psi^*(s)\boldsymbol{\sigma}\psi(-s)+\psi^*(-s)\boldsymbol{\sigma}\psi(s)$, which satisfy a five-dimensional continuity equation. The non-negative operator, $-\partial^2/\partial s^2$, is a constant of the motion; its eigenstates with eigenvalue $m^2\neq0$ have a one-to-one correspondence with the Dirac equation, with $-i\partial/\partial s$ replacing $m\gamma_4$. The eigenstates of mass 0 satisfy the wave equation for the two-component neutrino. In the corresponding field theory, particles of different masses are the quanta of the same field. The introduction of an interaction Hamiltonian which is of fourth order in this field operator, such as $\int d^3x ds \rho^2(x,s)$ permits the description of beta-decay processes. Calculations of the physical consequences of this theory are in process.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**Q6. Sigma-Nucleon $T=3/2$ Force.*** M. T. VAUGHN, *Purdue University.*—The sigma-nucleon force in the $T=\frac{3}{2}$ state is computed in the static approximation for one- and two-pion exchanges. The resulting singlet and triplet central potentials satisfy $V^1\approx3V^3<0$; the tensor force is relatively weak. The $V^1$ is very similar to the $^1S$ nucleon-nucleon potential but is about 10% larger in magnitude if the $\pi-\Sigma$ coupling is equivalent to $\pi-N$, because of differences in the two-pion term. Sigma-nucleon binding is further enhanced by the increased mass of the sigma (relative to nucleon-nucleon); these two features are sufficient to yield an $n-\Sigma^-$ binding of order 1 Mev. If the $n-\Sigma^-$ binding exceeds $\frac{1}{2}$ Mev, the $p-\Sigma^+$ should also be bound. For a cutoff radius of order $0.35\,\mu$ the $K$-exchange forces are negligible if $G_K^2/4\pi\approx1$.

* Assisted by the Air Force Office of Scientific Research.

**Q7. $D$-Wave Effect on the Dispersion Equation Analysis of the $\pi^-$-P Scattering.*** HOWARD J. SCHNITZER† AND GEORGE SALZMAN, *University of Rochester.*—A recent analysis of the $\pi^--P$ scattering data by the Bologna group[1] indicates that the forward scattering amplitude does not satisfy the dispersion relation given by Goldberger[2] for any value of the coupling constant. Charge dependent effects are too small to resolve the discrepancy.[3,4] We find that inclusion of $D$ waves in the analysis of the published experimental nuclear cross sections is insufficient, by itself, to remove the difficulty. Furthermore, a phenomenological treatment of the zero-energy $S$-wave scattering lengths, and of a possible high-energy contribution to the dispersion integrals shows that no reasonable choice of these parameters will lead to a unique

coupling constant consistent with the present experimental data.

* Supported in part by the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow 1957–1958.
[1] G. Puppi and A. Stanghellini, Nuovo cimento **5**, 1305 (1957).
[2] M. L. Goldberger, Phys. Rev. **97**, 508 (1955).
[3] A. Agodi and M. Cini, Nuovo cimento **5**, 1256 (1957); with Agodi, Cini, and Vitale, Phys. Rev. **107**, 630 (1957).
[4] G. Chew and P. Noyes, Berkeley Report UCRL-3869 (July, 1957).

**Q8. Analysis of *S*-Wave Neutron Scattering Resonances in the kev Region.*** CARL T. HIBDON, *Argonne National Laboratory.*—A new method of analysis has been developed on the basis of the single-level dispersion theory. With it most of the points of a resonance can now be used, provided the resonance is sufficiently isolated and resolved. The parameters $\Gamma$, $E_r$, and $\delta_l$, are expressed in terms of $\Gamma_m$, $E_m$, and $\delta_m$, where $m$ designates their values at the energy for which $\sigma_s$ is a maximum. The single-level expression can then be written in the form:

$$Y \equiv \pm\left[\frac{\sigma_s-\sigma_{\min}}{\sigma_m-\sigma_{\min}-(\sigma_s-\sigma_{\min})E/E_m}\right]^{\frac{1}{2}}|E-E_m| = a\Gamma_m/2+b(E-E_m)\tan\delta_m,$$

where $b\equiv[1-(\Gamma_m/2E_m)\tan\delta_m]^{-1}$ and $a\equiv b\sec^2\delta_m$. A plot of $Y$ *vs* $E$ is linear. From the slope of the line and the value of $Y$ where $E=E_m$ one obtains tentative values of $\tan\delta_m$ and $\Gamma_m$, respectively, since $b\approx a\approx 1$. These values lead to better values of $b$ and $a$ and hence $\Gamma_m$. Finally $\sigma_p$ may be calculated by use of the fact that $\delta=\delta_m$. The results for a number of resonances will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**Q9. Width of the Photonuclear Giant Resonance.** M. DANOS, *National Bureau of Standards.*—Wildermuth[1] calculated the friction constant $\Gamma$ which determines the width of the giant resonance by considering the decrease of the *n-p* collision probability inside the nucleus due to the Paul principle. Assuming the nuclear matter to be at a sufficiently high temperature he found $\hbar/t\equiv\Gamma\sim A^{-1/3}$. However, after absorption of a photon the nucleus has zero temperature; the time it takes the nucleus to heat up is $\hbar/t'\equiv\Gamma'\sim A^{-4/3}$ for large $A$. For $A=200$, $\Gamma'$ has the not too certain value of $\approx 1$ Mev. Thus the effect of volume friction is determined by the time $t'$, which has an $A$ dependence and magnitude in disagreement with experiment. Presumably the damping for heavy nuclei, therefore, occurs mainly in the surface where the density is below the normal nuclear density. This does *not* occur via excitation of surface waves, but probably in a straightforward irreversible process. Such a damping mechanism would allow the two modes in a deformed nucleus to have different widths, since their flow pattern is different. Consequences of this could possibly be detected experimentally.

[1] K. Wildermuth, Z. Naturforsch. **10a**, 447 (1955).

**Q10. Theorem on Minimum Elastic Cross Section.** WILLIAM RARITA, *RIAS, Inc.*—In the framework of the formalism of complex phase shifts, the minimum elastic cross section $\sigma_e$ for a two-particle scattering process ($p-p$, $p-p,\pi-p$, etc.) is found under the conditions that the total cross section $\sigma_T$ be fixed and that all the phase shifts $\delta_l$ vanish for $l>L$. This effectively gives the smallest value of $L$ consistent with a given set of $\sigma_e$ and $\sigma_T$. It was found that the associated phase shifts are all equal and pure imaginary ($i\alpha$) so that the case considered is equivalent to that of a gray disk. If we let $f$ be $2\sigma_e/\sigma_T$, then $\sigma_T$ is equal to $f$ times the $\sigma_T$ for a black disk ($\alpha\to\infty$), and the elastic angular distribution is $f^2$ times the corresponding angular distribution for a black disk. If we insert the experimental values for $\sigma_e$ and $\sigma_T$, we can determine a minimum interaction radius $R\sim(L/k)$ (that of the gray disk) or a minimum $L$ required for the phase shift analysis. We applied our theorem to $p-p$ at 452 Mev with $\sigma_e\sim 10$ mb and $\sigma_T\sim 100$ mb and obtain $R\sim$classical electron radius. For $\pi-p$ at 1.5 Bev with $\sigma_e\sim 10$ mb and $\sigma_T\sim 34$ mb, we get $L\sim 11$. For 1 Bev[1] $p-p,\sigma_e\sim 22$ mb, and $\sigma_T\sim 48$ mb, we find $L\sim 3$.

[1] W. Rarita, Phys. Rev. **104**, 221 (1956).

**Q11. Optical Model for Antiproton-Proton Scattering.** P. SCHWED, *RIAS, Inc.*—The experimental results currently available from Bevatron experiments for the total and annihilation cross sections[1] between protons and antiprotons at 450 Mev and for the total cross section[2] between 190 Mev and 700 Mev admit of interpretation in terms of a wave optical model of the interaction. Taking the elastic cross section at 450 Mev as the difference between the total (105 mb) and the annihilation (89 mb), the results for the parameters of a purely absorptive medium (corresponding to a purely imaginary potential) are uniquely $KR=0.5$ and $R=2.5\times10^{-13}$ cm where $K$ is the absorption coefficient and $R$ the radius of the region of interaction. If the quantity $K$ is assumed to vary as $1/k$ ($\mathbf{k}$ the propogation vector), it is possible to estimate the energy dependence of the cross section and to obtain reasonable agreement with the measured energy variation. The introduction of a real part of the potential would increase the value of $R$ and worsen the agreement for the energy dependence.

[1] O. Chamberlin, Seventh Annual Rochester Conference (1957).
[2] Cork, Lambertson, Picconi, and Wenzel, Phys. Rev. **107**, 248 (1957).

**Q12. Scattering of Protons in a Spin-Orbit Potential.*** G. W. ERICKSON AND W. B. CHESTON, *University of Minnesota.*—An approximation method has been developed for calculation of the proton polarization produced in elastic scattering in a spin-orbit potential. The method is a perturbation method in the sense that the spin-orbit potential is considered small compared to the central part of the proton potential which is handled by exact methods. For this reason, the method is not applicable to proton energies $\geq$100 Mev; exact calculations for this region have been reported. Results of calculations for proton energies in the range $10\leq E_p\leq 40$ Mev will be presented. The method will be compared with an exact calculation at 14 Mev. The approximate and exact calculations at this energy are experimentally indistinguishable. In the energy region considered, the polarization is essentially independent of the shape of the spin-orbit term; the equivalence between several shape factors will be demonstrated. The effect of the spin-orbit term on the elastic cross section will be discussed. Spin-orbit well depths of the order of magnitude needed for the bound state and high-energy scattering phenomena affect the elastic scattering at back angles in such a way as to make possible better fits of optical model calculations to experimental data as has been conjectured previously.

* Supported in part by U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Brown Auditorium

(J. A. KRUMHANSL presiding)

## *Symposium of the Division of Solid-State Physics*

## *Solid-State Information from Low-Temperature Experiments*

**R1. Thin Films as an Approach to Solid-State Physics.** R. E. GLOVER, *University of North Carolina.* (30 min.)

**R2. The Nature of Low-Temperature Electrical Conductivity in *n*-Type Germanium.** S. H. KOENIG, *IBM Watson Laboratory.* (30 min.)

**R3. Magnetic Properties and Band Structure of Graphite.** J. W. MCCLURE, *National Carbon Research Laboratories.* (30 min.)

**R4. Low-Temperature Studies of Mechanical Properties of Metals.** D. K. HOLMES, *Oak Ridge National Laboratory.* (30 min.)

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SATURDAY AFTERNOON AT 1:30

Wilson Auditorium

(J. S. KOEHLER presiding)

## *Irradiation Effects*

**S1. Influence of Mass Ratio on the Disordering of Diatomic Solids.*** E. M. BARODY, *Battelle Memorial Institute.*—Harris[1] investigated the disordering of polyatomic solids by high-energy radiation. For a compound of type $AB$, he calculated the number of displacements produced by a primary knock-on for various ratios of atomic masses. Isotropic scattering, equal cross sections for collisions of like and unlike atoms, and a single threshold energy for displacement were assumed. Even for this case, results for an arbitrary mass ratio could be obtained only by numerical integration. The present treatment follows the pattern established by Harris, but introduces threshold energy in the manner of Kinchin and Pease.[2] Simpler equations are obtained, and asymptotic solutions have been found for all mass ratios by the Laplace transform method. The difference between the numbers of $A$ and $B$ atoms displaced by a high-energy $A$ atom is particularly interesting. When the mass of the heavy atom is more than about ten times that of the light, the difference increases as a fractional power of the energy of the primary atom. For smaller mass ratios, the difference approaches a constant.

* Supported by Wright Air Development Center, Air Research and Development Command, U. S. Air Force.

[1] E. G. Harris, Naval Research Laboratory Report 4807, August 3, 1956.

[2] G. H. Kinchin and R. S. Pease, Repts. Progr. Phys. **18**, 1 (1955).

**S2. Changes in Mobility of Charged Carriers Produced by Deuteron Irradiation of Silicon.** T. A. LONGO, *Purdue University.*—Previous work has indicated that the effects of deuteron irradiation on the carrier concentration of *n*- and *p*-type silicon could be understood by the creation of Frenkel defects, which appear to introduce states very close to both carrier bands, and aggregates which appear to introduce deeper-lying states.[1] In addition to changes of carrier concentration, very striking irradiation effects of the Hall mobility have been observed. The Hall mobility of degenerate samples decreased monotonically. However, the Hall mobilities of nondegenerate samples decreased initially, then passed through a minimum (at $E_v - \zeta = 0.23$ ev for *n*-type samples and $\zeta - E_v = 0.25$ for *p*-type samples) and finally slowly decreased again. This minimum in the Hall mobility for the nondegenerate samples is most pronounced in the *p*-type samples and after heavier irradiations, as was the case in the earlier work with the effects which were believed to be associated with aggregation of defects.[1] The analysis of the data which is not associated with the Hall mobility minimum supports the belief that the shallow states are due to vacancy-interstitial pairs.

[1] T. A. Longo and K. Lark-Horovitz, Bull. Am. Phys. Soc. Ser. II, 2, 157 (1957).

**S3. Alpha-Particle Irradiation of Germanium at 4.2°K. II. Annealing.*** G. W. GOBELI, *Purdue University.*—Thermal annealing in degenerate *n*-type and *p*-type germanium samples after irradiation at 4.2°K was studied up to 78°K. Isochronal annealing indicates that no measurable thermal recovery occurs in any sample for annealing temperatures below 22°K and subsequent annealing at 20.4°K for 24 hr confirms this result. Definite thermal recovery is observed by annealing at 25°K for 20 minutes. Experiments at 78°K show that the amount of thermal recovery of radiation induced carrier concentration changes in *n*-type and *p*-type samples is essentially the same (25% and 22%). Electrical resistivity measurements taken while the samples were warmed up to 78°K indicate two distinct regions of thermal recovery, with maximum rates of change occuring near 32°K and 66°K. Subsequent isothermal annealing at 26°K, 33°K, and 50°K confirms that the two regions are completely separable. The low-temperature process is found to follow a first-order reaction with a unique thermal activation energy of about 0.015 ev. The higher temperature process does not yield to simple analysis.

* Work supported by U. S. Signal Corps.

**S4. Alpha-Particle Irradiation of Germanium at 4.2°K. I. Irradiations.*** K. LARK-HOROVITZ AND G. W. GOBELI, *Purdue University.*—Employing a sealed polonium-210 alpha-particle source having an effective energy of 3.73 Mev, degenerate *n*-type and *p*-type germanium samples were irradiated at

4.2°K. The temperature was maintained by admitting small amounts of helium exchange gas to the sample-source chamber. In samples held for 20 hr at 4.2°K following irradiation no changes in the electrical properties were observed. Carriers were removed in both *n*-type and *p*-type material, showing a linear dependence on flux up to 50% carrier concentration changes. Removal rates calculated from Hall coefficient give $2.84\times10^{4}$ electrons/alpha particle-cm in *n*-type samples and $0.662\times10^{4}$ holes/alpha particle-cm in *p*-type samples. A calculation of lattice displacements, employing a displacement threshold energy of 30 ev, yields $2.79\times10^{4}$ displacements/alpha particle-cm. The Hall mobility in both *n*-type and *p*-type material exhibited a marked decrease during the irradiations. The mobility changes in *n*-type samples are much larger and more sensitive to the irradiation flux than in *p*-type material.

* Work supported by U. S. Signal Corps.

**S5. Fast Neutron Irradiation of Aluminum Antimonide.*** F. J. REID, A. C. BEER, AND R. K. WILLARDSON, *Battelle Memorial Institute.*—Electrical conductivity, Hall effect, and magnetoresistance were measured as a function of temperature between 50 and 450°K before and after irradiation by fast neutrons up to $2\times10^{18}$ nvt. Both *p*- and *n*-type single crystals with initial carrier concentrations from $1.5\times10^{17}$ to $2\times10^{18}$ carriers/cm³ were studied. Conversion of *p*- to *n*-type suggests production of shallow electron traps with center of gravity of donor and acceptor traps lying above the center of the forbidden gap. After irradiation two unique types of behavior were observed for the Hall mobilities of the holes: (1) low mobility, relatively independent of temperature, or (2) a rapid decrease in mobility with decreasing temperature. However, mobility determined from magnetoresistance data did not exhibit these anomalies. This indicates that Hall data on neutron-bombarded semiconductors must be used with caution. Further problems regarding the interpretation of Hall data are demonstrated after annealing, when the Hall coefficient is found to decrease with decreasing temperature. Behavior of the Hall coefficient in bombarded *p*-type AlSb is explained on the basis of Frenkel defects and *n*-type microregions of concentrated defects.

* Supported by Wright Air Development Center, Air Research and Development Command, U. S. Air Force.

**S6. Radiation Effects in α-$Al_2O_3$ as Indicated by Neutron Transmission Spectra.** J. J. ANTAL, *Ordnance Materials Research Office,* AND A. N. GOLAND, *Brookhaven National Laboratory.**—The slow neutron transmission spectrum of α-$Al_2O_3$ irradiated in the Brookhaven reactor at a temperature less than 40°C was obtained from 4.6 to 10 A for several levels of fast neutron bombardment. The largest irradiation dose was $1.4\times10^{19}$ neutrons per cm². The material was thereafter annealed in stages and examined by transmission with a beam of filtered neutrons having an effective wavelength of 8.4 A. The number of defects remained constant until a temperature of approximately 400°C was reached, then reduced slowly with increasing temperature beyond this point. The previously noted surprisingly low concentration of defect scatterers in this material[1] made it difficult to obtain good accuracy in a determination of the wavelength dependence of the transmission; still, an attempt was made to ascertain the character of the defects by analysis of this data.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. J. Antal and G. J. Dienes, Bull. Am. Phys. Soc. Ser. II, 2, 151 (1957).

**S7. Low-Temperature Electron Irradiation of Copper.** J. W. CORBETT, R. B. SMITH, AND R. M. WALKER, *General Electric Research Laboratory.*—Irradiations with 1.4-Mev electrons performed on high-purity copper maintained at 20.4°K are shown to be equivalent to irradiations performed at 12°K in that the same (±½%) linear production rate is obtained. Irradiations performed at 80°K confirm that to a total dose of $4\times10^{17}$ (elec/cm²) the production rate decreases monotonically with increasing dose.[1] For the same total electron dose, less resistivity increment is produced by an irradiation at 80°K than by an irradiation at 20.4°K followed by an anneal at 80°K. It is further shown that the recovery of 20.4°K irradiation damage during isothermal annealing at 55°K can be affected by doping the specimen by irradiating at 80°K before the 20.4°K irradiation is performed. The magnitude of the recovery and the rate of recovery are increased by the preirradiation at 80°K. These results are inconsistent with a model in which only close pairs recover below 80°K. The implications of these results as to the motion and interaction of the radiation-induced defects will be discussed.

[1] C. J. Meechan and J. A. Brinkman, Phys. Rev. 103, 1193 (1956).

**S8. Isothermal Annealing below 60°K of Deuteron-Irradiated Noble Metals.*** G. D. MAGNUSON, J. S. KOEHLER, AND W. PALMER, *University of Illinois.*—Isothermal annealing between 10°K and 60°K of the electrical resistivity increments produced by 10.7-Mev deuteron irradiation was carried out on foils of pure Cu and Ag and a foil of Cu with 3.78 at % Ni. The ratio $\rho0°C/\rho4.2°K$ of the Cu was 1110 and that of the Ag was 798. During irradiation the Cu and Ag foils were maintained at a temperature less than 10.8°K and the CuNi foil at a temperature less than 21.1°K. The annealing was performed in a series of isothermal steps, each of about one hour's duration. The interval between steps was about 1.5°K. The temperature at each step was maintained constant to ± 0.02°K. The resistances could be read to 0.11% and 0.070%, of the maximum observed resistance increments in the Cu and Ag, respectively. No annealing occurred in Cu between 45°K and 78°K, the amount remaining being about 33%. In Ag some annealing did occur between 35°K and 78°K, the amount remaining at 50°K being about 52%. Alloying tended to make the annealing more nearly a continuous process with a wide range of energies.

* This work was partially supported by the U. S. Atomic Energy Commission.

**S9. Change in the Debye Characteristic Temperature of Deuteron-Irradiated Cu and Ag.*** J. S. KOEHLER, W. PALMER, AND G. D. MAGNUSON, *University of Illinois.*—The isothermal annealing data of 10.7-Mev deuteron-irradiated Cu and Ag foils show discontinuities between successive anneals which represent a change in the lattice vibration spectrum and can be interpreted most easily as a change in the resistive Debye characteristic temperature. The thermal part of the resistivity of the foils after bombardment, at a temperature $T$ low enough so little annealing of the resistivity increment has occurred, can be obtained by adding to the thermal part of the resistivity of the foils before bombardment the sum of the discontinuities up to that temperature. Thus, curves of $\rho_T T$ *versus* $T$ can be obtained for the foils before and after bombardment. Expressing the thermal part of the resistivity as a Bloch-Gruneisen function, $\rho_T T$ is a function only of $T/\theta$, where $\theta$ is the resistive Debye characteristic temperature. Hence, a comparison of the $\rho_T T$ curves before and after bombardment will yield a value of the Debye characteristic temperature of the bombarded metals. For Cu the $\Delta\theta$ was $-(15\pm1)$°K, and for Ag the $\Delta\theta$ was $-(10\pm1)$°K. An estimate of the annealing of the decrease in the Debye characteristic temperature can also be obtained which shows that 80–90% of the observed $\Delta\theta$ anneals out upon warming to 50°K.

* This work was partially supported by the U. S. Atomic Energy Commission.

**S10. Activation Energy Spectra and Frequency Factors of Deuteron-Irradiated Cu and Ag.*** W. PALMER, G. D. MAGNUSON, AND J. S. KOEHLER, *University of Illinois.*—An analysis of the data obtained in low-temperature (10°K–60°K) isothermal annealing of the radiation-induced resistivity increment in 99.999% pure Cu and Ag shows the existence of processes (which may or may not be alike) with differing activation energies. Resistivity density curves were determined by assuming that processes with a continuum of activation energies are present in the irradiated metals. These curves show several small peaks followed by a large peak. The maxima occur in Cu at 0.048, 0.080, 0.091, and 0.113 ev. In Ag the peak maxima occur at 0.045, 0.058, and 0.079 ev. The frequency factor $(A/a)$, where $A$ is the atomic vibration frequency and $a$ is the average number of jumps required by a defect to reach an annihilation or trapping center, was found to be large, having a value in the range $7.2\times10^{10}$ to $3.9\times10^{13}-1$ sec$^{-1}$. The dominant mechanism in the low-temperature annealing seems to be the annihilation of Frenkel pairs, with the interstitials as the mobile defects. A trapping model is proposed to explain why all the resistivity increment does not anneal out once interstitials begin to move.

* This work was partially supported by the U. S. Atomic Energy Commission.

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SATURDAY AFTERNOON AT 1:30

Louderman Auditorium

(A. H. WEBER presiding)

## *Neutron Physics*

**T1. Measurements of the Po-Be Neutron Spectrum with a Proton Recoil Spectrometer.** R. J. BREEN,* M. R. HERTZ,† AND D. U. WRIGHT, JR.,‡ *Mound Laboratory.*§—Po-Be neutron sources were prepared by volatizing $Po^{210}$ into an empty nickel container. The beryllium target material was added after which the container was closed and sealed by coating with nickel. The container was then heated to distribute the polonium throughout the target material. A proton recoil neutron spectrometer operating in the range 1.3 to 11 Mev was used to measure the neutron spectrum of several Po-Be neutron sources. The average energy of the neutrons is about 4.5 Mev. An analysis of the spectrum indicates that 70% of the neutrons are accompanied by a 4.4-Mev gamma ray. No variation in the spectrum within the resolution of the spectrometer is observed in the various sources studied.

* Now at Westinghouse Bettis Atomic Power Division.
† Now at Goodyear Atomic Corporation.
‡ Now at Aberdeen Proving Grounds.
§ Operated for the U. S. Atomic Energy Commission by Monsanto Chemical Company.

**T2. Inelastic Scattering of Neutrons on $Na^{23}$.** E. SHIPLEY, G. E. OWEN, AND L. MADANSKY, *The Johns Hopkins University.*—A sodium iodide scintillation crystal is bombarded with 3.9-Mev neutrons. The gamma rays from the excited states in Na and I are detected in the NaI target, while the scattered neutrons are detected in a stilbene counter, which can be rotated about the target. Pulses from the NaI crystal are gated by a fast coincidence circuit operating between the two counters. The resulting spectrum shows peaks due to the 439-kev state in Na, and the 340-kev and the 630-kev states in I. The peak from Na state is shifted in energy due to the recoil energy of the scattering nucleus. The efficiency for conversion of the Na recoil energy to light is measured to be 30% of that efficiency for electrons. The recoil energy of I is not observable. The 439-kev gamma ray from Na is observed without the associated recoil energy by surrounding the NaI target with sodium metal, so that the scattering nucleus is external to the scintillator. The total cross section for inelastic scattering of 3.9-Mev neutrons from the 439-kev state in Na is measured to be $0.14-0.05+0.1$ barn. Angular distributions of the inelastically scattered neutrons will be presented.

**T3. Fast Neutron Scattering from Fe and $Pb^{204}$ by Time-of-Flight.*** A. J. ELWYN, G. N. GLASOE, H. H. LANDON, AND S. OLEKSA, *Brookhaven National Laboratory.*—The 3-Mev phase-bunched proton beam from the BNL 18-in. cyclotron has been used to produce 2.2-Mev neutrons in the $T(p,n)He^3$ reaction. A time-of-flight technique, involving the use of a time-to-pulse-height converter in conjunction with a 100-channel quartz line pulse-height analyzer, has been employed to study the elastic and inelastic scattering of neutrons from spherical targets of Fe and $Pb^{204}$. The operation of the detector system has been described previously.[1] Results will be presented giving the elastic and inelastic differential cross sections in Fe. The neutron angular distribution leaving $Fe^{56}$ in a state at 0.845 Mev is shown to be isotropic to about 1%. Three levels in $Pb^{204}$ have been observed at 0.80, 1.35, and 1.46 Mev. Angular distributions of the neutrons corresponding to these levels will be shown, as well as the elastic distribution. Preliminary results indicate that the levels at 1.35 and 1.46 Mev show isotropy in their distribution, while the state at 0.80 Mev appears to be slightly anisotropic but symmetric about 90°.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Landon, Elwyn, and Glasoe, Bull. Am. Phys. Soc. Ser. II, 2, 233 (1957); Glasoe, Landon, Elwyn, and Oleksa, *Conference on the Neutron Interaction with the Nucleus* (Columbia University, New York, September, 1957).

## *Invited Papers*

**T4. Neutron Capture Reactions in the Laboratory and in Stars.** A. G. W. CAMERON, *Chalk River Laboratory.* (30 min.)

**T5. Gamma Rays Following Resonant Neutron Capture.** H. L. SCHULTZ, *Yale University.* (30 min.)

**T6. Experimental Tests of Fission and Reaction Theory for Slow Neutrons.** L. M. BOLLINGER, *Argonne National Laboratory.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Wayman Crow, 101

(H. PRIMAKOFF presiding)

## *Theoretical Physics, II*

**U1. Relative Phase of the Delbrueck Scattering Amplitude.** C. WERNTZ AND W. B. CHESTON, *University of Minnesota.*—Precise measurements on the elastic scattering of $\gamma$ rays from atomic nuclei have recently been reported[1] indicating effects attributable to Delbrueck scattering (i.e., potential scattering of $\gamma$ rays). The Delbrueck amplitude in the forward direction has been calculated[2,3] previously using the techniques of fourth-order quantum electrodynamics and dispersion theory. The equivalent vacuum polarization Hamiltonian which is fourth order in the field strengths[4] has been used in first order to calculate the Delbrueck amplitude over the entire angular range for energies below the pair production threshold. The phase of the forward amplitude thus calculated agrees with that obtained previously. There is no evidence for a change in sign of the Delbrueck amplitude for scattering angles less than 90° in apparent contradiction with experiment.

[1] A. K. Mann, Bull. Am. Phys. Soc. Ser. II, **2**, 5 (1957).
[2] F. Rohrlich and R. Gluckstern, Phys. Rev. **86**, 1 (1952).
[3] H. A. Bethe and F. Rohrlich, Phys. Rev. **86**, 10 (1952).
[4] H. Euler and B. Kockel, Naturwissenschaften **23**, 346 (1935).

**U2. Estimate of Nuclear Finite Size Effect on Internal Conversion Coefficients by Configuration Mixing.** L. S. KISSLINGER,* *Western Reserve University.*—T. A. Green and M. E. Rose[1] have expressed the internal conversion coefficients for various electric and magnetic transitions in such a way that the nuclear structure effect can be readily calculated for a particular nuclear model. The form of the results indicates that the $l$-forbidden transitions might display a nuclear structure dependence.[2] Using configuration mixing,[3] the relevant matrix elements have been calculated for certain $l$-forbidden transitions. A detailed calculation for the 279-kev $M1$ transition in $Tl^{203}$ gives about a 10% effect when compared to Sliv's coefficients.

* The work was done during the summer, 1957, while the author was a research participant at the Oak Ridge National Laboratory.
[1] T. A. Green and M. E. Rose (to be published).
[2] See also E. L. Church and J. Weneser, Phys. Rev. **104**, 1382 (1956).
[3] Arima, Horie, and Sano, Progr. Theoret. Phys. **17**, 567 (1957).

**U3. Second-Forbidden Matrix Elements in the Beta Decays of $P^{32}$ and $C^{14}$.*** B. C. CARLSON AND GEORGE B. HENTON, *Iowa State College.*—Interference between beta-decay matrix elements having different orders of forbiddenness may be significant in decays with anomalously large $ft$ values, such as $P^{32}$ and $C^{14}$. If $|\int\beta\sigma|^2$ is very small, the interference terms between $\int\beta\sigma$ and second-forbidden matrix elements, such as $\int(\beta\sigma\cdot\mathbf{r})\mathbf{r}$ and $\int\beta\sigma\times\mathbf{r}$, are not negligible, and their energy-dependent coefficients in the electron spectrum are greatly increased by Coulomb corrections. The resulting deviations from allowed shape have been calculated, for either sign of the interference, from assumed nuclear wave functions and (to obtain $|\int\beta\sigma|$) experimental $ft$ values. For $P^{32}$ the calculated shape factor varies almost linearly with energy by 9% between 0.3 Mev and 1.6 Mev. Experimental shape factors obtained at the Argonne[1] and Ames[2] Laboratories decrease in the same energy range by only 3% and 2% respectively, but are consistent with linear energy dependence. For $C^{14}$ calculated deviations[3] from allowed shape amount to +2% or −1%, depending on the relative sign of $\int\beta\sigma$. The interference terms make an important contribution to the decay probability of $C^{14}$ and, to a lesser extent, of $P^{32}$.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Porter, Wagner, and Freedman, Phys. Rev. **107**, 135 (1957).
[2] Iowa State College Report ISC-833 (unpublished).
[3] Iowa State College Report ISC-758 (unpublished).

**U4. Effect of Detour Transitions on the Spectrum of Inner Bremsstrahlen.*** G. W. FORD, *University of Notre Dame,* AND R. R. LEWIS, *Institute for Advanced Study.*—In attempting to understand the large discrepancy between theoretical predictions and experimental measurements of the spectrum of inner bremsstrahlen accompanying beta decay the effects of the so-called detour transitions have been considered. These are transitions in which the nucleus first emits a photon, going to a *virtual* excited state, and then $\beta$ decays, or vice versa. One can readily convince oneself that the detour transitions are negligible in the case of an allowed beta transition but will contribute significantly to the spectrum of inner bremsstrahlen for a forbidden transition. Detailed computations have been carried out for the case of the unique first-forbidden transitions ($\Delta J=2$, yes), and the corrections are indeed found to be important, being greater than 100% beyond the midpoint of the spectrum. Comparisons with the experimental work of Hokeem and Goodrich[1] on $Y^{90}$ will be made.

* Supported in part by the U. S. Atomic Energy Commission.
[1] M. Goodrich and M. A. Hakeem (to be published).

**U5. Quasi-Resonance and Various Approximations in the Anderson Theory of Pressure Broadening.*** L. J. KIEFFER† AND A. V. BUSHKOVITCH, *Saint Louis University.*—Because of the difficulty of applying the P. W. Anderson theory of pressure broadening simplifications have been proposed.[1] In a recent article by Perkins, Bushkovitch, and Kieffer[2] a simplified theory was outlined in detail and applied to three cases of foreign gas broadening of linear molecules. This paper presents an analysis of this simplified theory and shows that it is equivalent to assuming that all partial cross sections for linear molecules are quasi-resonant and equal to the quasi-resonant partial cross section for large $J_2$. With this general conclusion as a guide five common van der Waals interactions between linear molecules are examined and a quantitative estimate of the errors involved in the use of the simplified theory is given.

* Supported in part by the Air Force Office of Scientific Research.
† Now at Argonne National Laboratory, Lemont, Illinois.
[1] W. V. Smith and R. Howard, Phys. Rev. **79**, 132 (1950).
[2] Perkins, Bushkovitch, and Kieffer, J. Chem. Phys. **26**, 779 (1957).

**U6. Stokes' and Einstein's Law for Nonuniform Viscosity.** S. BROERSMA, *Northwestern University.*—With a viscosity dependence upon the distance $r$ to a sphere in a fluid

$$\eta_\infty/\eta(r)=1-\epsilon(a/r)^m$$

it approximately holds: force upon translating sphere

$$6\pi v\eta_\infty a[1+(1-4m/(m+3)(m+5))\epsilon/(m+1)]$$

torque upon rotating sphere

$$8\pi\omega_0\eta_m a^3[1+3\epsilon/(m+3)]$$

relative viscosity of suspension

$$1+\epsilon(a/R)^m 3/(3-m)+5/2(a/R)^3[1+1.8\epsilon/(m-3)].$$

**U7. First Law of Thermodynamics, M. Planck and Mathematics.** M. Z. v. KRZYWOBLOCKI, *University of Illinois* (introduced by R. D. Hill).—Using a very vague notion of a differential (without explaining whether it is total or (exact) perfect) Max Planck in his book on thermodynamics opposes the proposal of Clausius in considering the expression for the heat input $dQ$ in the First Law of Thermodynamics $dQ = dU + dW$ as a differential of a function $Q$, and supposedly shows that $dQ$ is not a differential. Some time ago Karl Menger, using the concept of the Stieltjes integral, had shown that $Q$ does not need to be a function of state (of $v$ and $T$), and hence $dQ$ is a total (but not exact) differential. The author demonstrates clearly the fallacy of Planck's proofs and points out the weak points in his reasoning.

***Post-Deadline Papers, If Any***

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## Preliminary Announcement of the 1957 Winter Meeting in the West

The Winter Meeting of the American Physical Society in the West is to be held at Stanford University on Thursday, Friday, and Saturday, December 19, 20, and 21, 1957. Deadline will be past when this notice appears; it has already been announced in two issues of the *Bulletin*. There is no official hotel for this Meeting, but package accommodations have been arranged for dormitory accommodations and meals. These arrangements are complicated because of other meetings of interest to physicists that will be taking place at about the same time in Stanford.

Those members of our Society who will be coming to Stanford can sign up for meals and housing for the duration of the Meeting for $28.16. This includes Wednesday through Saturday night housing, the 18th through the 21st of December, and includes Thursday morning breakfast and the Saturday evening dinner, but does not include dinner on Friday night, the night of the banquet of the Society.

Since the Conference on Nuclear Sizes will be taking place on the Tuesday, Wednesday, and Thursday of the same week, similar arrangements are being made for the participants of that Meeting. For those individuals who plan to attend both Meetings, combination living arrangements that will include both Meetings will cost a total of $42.08 and will include housing from Monday through Saturday nights and meals beginning with breakfast on Tuesday the 17th and ending with dinner Saturday the 21st, except for the banquets.

On Monday, December 16th, there will be a Symposium on Magneto Hydrodynamics arranged by the Lockheed Aircraft Corporation, Missile Systems Division, in Palo Alto.

Those individuals living "off campus," or presumably staying at local hotels or motels, may, if they wish, make a prepaid luncheon arrangement for the three luncheons with either group or the five luncheons with both groups at a cost of $2.08 per luncheon or $6.24 for three, or $10.40 for the five. These campus lunches are for groups of three or five. "Single" lunches can be had only at the "Cellar" on campus or off campus.

The chairman of the local committee in charge of these arrangements is Professor S. D. Drell. All inquiries for reservations should be made to Dr. John M. Yarborough, Director of Residences, Stanford University, Stanford, California. Those desiring information on motel or hotel accommodations, other than residence halls, should write Professor Drell.

The programme of invited papers is expected to include sessions on nuclear and paramagnetic resonance, biophysics, high-energy physics, electron theory, and electron physics.

W. A. NIERENBERG
*Local Secretary for the Pacific Coast*

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## Preliminary Announcement of the 1958 Annual Meeting

The 1958 Annual Meeting of the American Physical Society will be held in New York City on Wednesday, Thursday, Friday, and Saturday, January 29, 30, 31, and February 1, 1958. Sessions will be held in the Hotel New Yorker, in the Manhattan Center, and in the Governor Clinton Hotel. The official hotel is the New Yorker. Make your reservations early and do not fail to say that you are coming to our meeting.

Deadline date for this meeting is Friday, November 15, and abstracts are to be sent to the office of the Society at Columbia University, New York 27, New York. This deadline date has already appeared in the "calendar of prospective meetings" in the June and September issues of this *Bulletin* (a remark here inserted because this issue might possibly be delayed in publication until the date is past).

## MEETINGS AND DEADLINES FOR THE SEASON 1957–58

| *Place* | *Meeting dates* | *Deadline date* |
|---|---|---|
| St. Louis | November 29–30 | past |
| Stanford,* California | December 19–21 | past |
| New York | January 29–February 1, 1958 | November 15 |
| Chicago | March 27–29 | January 17 |
| Washington | May 1–3 | February 21 |
| Ithaca, New York | June 19–21 | April 18 |
| Vancouver, *British Columbia | August 26–28 | June 27 |
| Los Angeles | December 18–20 | October 17 |

* Abstracts for the Stanford and Vancouver meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline-day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

## RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; one must be an original, the other may be an original or a carbon copy. *They must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *If we receive an abstract typed on two pages, we print only its first page.* Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It now becomes an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

## Statement by the 1957 Nominating Committee

The Nominating Committee feels that perhaps it is appropriate to explain why it proposes more nominees than positions to be filled in the case of Councillors, but not for the other positions. It is a tradition of long standing in the Society that the outgoing Vice-President become the new President. The selection of the new Vice-President thus involves essentially the choice of the President a year hence. Since this position is the Society's highest honor, the Committee felt that a "popularity contest" for this office would be lacking in dignity and would serve no useful purpose, especially since questions of policy are decided by the Council rather than the executive officers. The positions of Secretary and Treasurer are managerial ones, in which continuity and experience are obviously desirable.

The selection of the Board of Editors involves delicate questions of balancing between the various disciplines. The editorial needs of various areas are not necessarily commensurate with the popularity of the fields. For instance, referees in special and general relativity are always urgently needed even though page-wise this subject does not bulk especially large in our journals. For this reason, the Nominating Committee always consults the Editor-in-Chief before making nominations for the Board of Editors. Those of great éclat in research are not necessarily very responsible referees. Usually proposed appointees have already been tried out by asking them to referee a paper or two. In some cases, the appointment to the Editorial Board is an *ex post facto* recognition of help already given.

The Council is the policy-making board of the Society, and in order to make sure that all viewpoints are adequately represented, a multiple choice is provided for positions on the Council.

In conclusion, it should be emphasized that any eligible name automatically appears on the ballot if nominated by "members of the Society numbering at least 1% of the total number of members given in the latest printed membership list of the Society." (The critical number is at present 118.) This proviso furnishes an obvious remedy in case an appreciable part of the membership is dissatisfied with the conduct of the Society.

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## Memorial

Esther L. Nelson, Office Manager of the American Physical Society at Columbia University for thirteen years, died on July 21, 1957, after an illness of only four days. She was introduced to the Society in 1944 by her predecessor in that office, having previously worked for the Sixth Avenue Association. During her earlier years with us she had, among other responsibilities, those of billing the members of the Society, of recording their choices of journals, and of preparing for Lancaster Press the addressographed envelopes or wrappers in which our journals were forwarded to them. These tasks she fulfilled with the aid of temporary help, usually the wives of graduate students who were available only for a year or two while their husbands were earning their degrees; thus Miss Nelson had over and over again the additional task of training new assistants, and the disappointment of losing them soon after they were trained. Over her desk passed innumerable letters from members whose bills or journals had gone astray, usually because they had failed to signify a change of address in time. After these tasks began to overtax the office they were transferred to the American Institute of Physics, but there still remained plenty to occupy Miss Nelson, for she was normally the entire office staff except in the period when the 1955 Membership List was being prepared. She was secretary to both the Secretary and the Treasurer of the Society, and she was expert in handling the routines of the Treasurer's office, such as the bookkeeping and the multitudinous forms required by Government. The latest three membership lists of the Society were her achievements, for she directed and took part in the preparation of each from start to finish.

# The American Physical Society

## OFFICERS OF THE SOCIETY FOR 1957

| | | |
|---|---|---|
| *President* | H. D. Smyth | Princeton University |
| *Vice-President* | J. W. Beams | University of Virginia |
| *Secretary* | K. K. Darrow | Bell Telephone Laboratories (*retired*) (Office at Columbia University) |
| *Treasurer* | S. L. Quimby | Columbia University |
| *Managing Editor* | S. A. Goudsmit | Brookhaven National Laboratory |

*Past Presidents now on Council:* W. F. G. Swann, H. A. Bethe, R. T. Birge, and E. P. Wigner.

*Elected Members of the Council:* John Bardeen, A. O. Nier, F. Seitz, A. M. Weinberg, S. K. Allison, N. F. Ramsey, Walker Bleakney, and W. K. H. Panofsky.

| | | |
|---|---|---|
| *Local Secretary for the Pacific Coast* | W. A. Nierenberg | University of California, Berkeley |
| *Deputy Secretary* | W. W. Havens, Jr. | Columbia University |

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***Please cut along this line***

**(To be sent to Professor John M. Fowler, Washington University, St. Louis, Missouri)**

I EXPECT to attend the dinner of the American Physical Society at seven o'clock on Friday evening, November 29. My party will comprise .... persons.

(*Name*).....

(*Address*).....

(If you want your tickets held to the time of the banquet itself, send a check, made out to American Physical Society, for $4.00 per plate.)